CHARLES UNIVERSITY IN PRAGUE

FACULTY OF SOCIAL SCIENCES

Institute of Economic Studies

Oldřich Veselý

Default Risk of Greek Government during the Crisis of 2010

Master Thesis

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Author: **Bc. Oldřich Veselý**

Supervisor: **doc. Ing. Oldřich Dědek, CSc.**

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Abstract

Many people have already questioned whether Greece would default: investors, economists, politicians and general public. The Greek debt crisis has also caused a great turmoil in the EU causing fears of its spreading to other countries with poor fiscal situation in Eurozone through bond markets. Finally the rescue package was prepared for Greece consisting of EUR 110 billion loan facility from both Eurozone and IMF.

We study the Greek fiscal crisis in the thesis. We try to find its real causes in the historical chapter and we also show the methodology which can be used to assess the credit risk of Greek government using bond market information and CDS contracts information. In the empirical part we study the evolution of the probability of default of Greek government during the debt crisis using parsimonious model based on the bond market information.

Keywords: bonds, CDS, default risk estimation, European Union, Eurozone, fiscal policy, Greek debt crisis, Greek government
Author's e-mail: oldves@gmail.com
Supervisor's e-mail: dedek@fsv.cuni.cz

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Abstrakt

Mnoho lidí si již položilo otázku, zda Řecko zbankrotuje: investoři, ekonomové, politici i veřejnost. Řecká dluhová krize také způsobila velký rozruch v EU, působící strach z jejího rozšíření do ostatních zemí Eurozóny se špatnou fiskální situací skrze trhy s dluhopisy. Nakonec byl pro Řecko připraven záchranný balíček, který je tvořen 110 miliardami EUR v podobě dluhové facility od Eurozóny a Mezinárodního měnového fondu.

V práci studujeme řeckou fiskální krizi. V historické kapitole se snažíme nalézt její skutečné příčiny a též ukazujeme metodologii, která může být použita k ohodnocení kreditního rizika řecké vlády pomocí informací z trhu s dluhopisy a pomocí informací z kontraktů swapů úvěrového selhání. V empirické části studujeme vývoj pravděpodobnosti bankrotu řecké vlády během dluhové krize pomocí parsimonního modelu založeného na informacích z trhu s dluhopisy.

Klíčová slova: dluhopisy, Evropská unie, Eurozóna, fiskální politika, odhad rizika úvěrového selhání, řecká dluhová krize, řecká vláda, swap úvěrového selhání

Autorův e-mail: oldves@gmail.com

E-mail vedoucího práce: dedek@fsv.cuni.cz

Počet znaků včetně mezer: 128 649

Declaration

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

The author hereby declares that this thesis was not used to obtain another title.

The author grants to Charles University permission to reproduce and to distribute copies of this thesis document in whole or in part.

Prague, 27 April 2011 Oldřich Veselý ____________________

Signature

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I would also like to thank the Institute of Economic Studies for providing me with an access to the Reuters Wealth Manager database.

Master Thesis Proposal

Institute of Economic Studies
Faculty of Social Sciences
Charles University in Prague

Author:	**Bc. Oldřich Veselý**	Supervisor:	doc. Ing. Oldřich Dědek CSc.
E-mail:	oldves@gmail.com	E-mail:	dedek@fsv.cuni.cz
Phone:	732 144 966	Phone:	222 112 326
Specialization:	Finance, Financial Markets and Banking	Defense Planned:	June 2011

Proposed Topic:

Default Risk of Greek Government during the Crisis of 2010

Topic Characteristics:

In recent years the fiscal situation of Greece has been continuously worsening. The government's budget deficit expanded to very high 13.6 % in 2009 (Eurostat) according to the newest information as the estimate was increased several times. Greek government bond markets reacted to the worsening of Greek's fiscal situation because of rising riskiness of Greek government bonds connected to the higher risk of their default. During the April 2010 Greek government bonds started to decline in value more dramatically causing their yields to rise significantly. But the rising yields meant higher costs of financing government debt for Greek government which caused government troubles with liquidity or even solvency. Because Greece is the member of Eurozone a big rescue package was negotiated in the form of loans with favorable interest rates for Greece from Euro area member states on 11 April with participation of IMF also. The package was negotiated because of the fears about possible contagion of Greek crisis through Eurozone. After doubts about the sufficiency of the size of the package it was significantly enlarged.

In the thesis I would like to study the period of Greek fiscal crisis from the perspective of Greek government bonds. Valuation of bonds is tightly connected to the probability of default of their issuer, which I would like to exploit and estimate the evolution of probability of default of Greek government during the crisis. The probability of default of Greece is a question many asked during the crisis and maybe still ask today as the crisis hasn't fully ended yet. I think that trying to answer this question is interesting and very up to date task.

Other way how we can estimate probability of default of government is to use credit default swap derivative instrument. It is why I will also discuss this instrument in the thesis to compare it with usage of bonds for this purpose.

The expected data sources I will use for purposes of the thesis are:

Reuters Wealth Manager, available at: <http://www.gva.rapid.reuters.com/wealthmanager> (access granted by IES FSV UK)

OECD Statistics, available at: <http://stats.oecd.org/Index.aspx>

ECB: Statistics, available at: <http://www.ecb.int/stats/html/index.en.html>

Eurostat Statistics Database, available at :
<http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database>

The main data source for bond pricing and bond yields, for example, but also as a source of news about Greek fiscal crisis will serve Reuters Wealth Manager. Other databases will serve as supplemental sources of information.

Hypotheses:

1. The probability of default of Greek government during the Greek fiscal crisis of 2010 rose significantly.
2. The probability of default of Greek government fell significantly after the announcement of the aid package for Greek government.
3. The probability of default of Greek government became stable after the announcement of the aid package for Greek government.

Methodology:

In the part of the thesis where I will provide an insight into the Greek fiscal crisis, methods of synthesis and analysis of various information sources will be used, mainly news articles from Reuters to ensure up to date and reliable information.

To verify or falsify aforementioned hypotheses a method similar to one of the term-structure approach methods proposed by Andritzky (2006) will be employed to model the probability of default of Greek government. The choice of method will depend on its performance on Greek government bonds dataset. Mainly, a proper hazard function has to be chosen which I expect will be a function based on parsimonious model of yield curve of Nelson and Siegel (1987).

Outline:

1. Introduction
2. Greek fiscal crisis of 2010
3. Various methods using bond market prices for evaluation of default risk
4. Using credit default swaps for evaluation of default risk
5. Application of selected bond based model using on the case of Greek crisis of 2010
6. Discussion of the results and conclusion

Core Bibliography:

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Author

Supervisor

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Acronyms

CDS	credit default swap
ECB	European Central Bank
EDP	excessive deficit procedure
EEC	European Economic Community
EU 27	first 27 countries joining the European Union
EU	European Union
GDP	gross domestic product
IMF	International Monetary Fund
ISIN	International Security Identification Number
OJ	Official Journal of the European Union
OTC	over the counter
RMSE	root mean square error
SEC	*acronym of the European Commission documents marked as "other"*
TEC	Treaty establishing the European Community
VBA	Visual Basic for Applications

Introduction

Recent world economic crisis has pronounced problems with debts of several countries with loose fiscal policies in the European Union, such as Greece, Ireland, Portugal, or Spain. The first country, where the crisis augmented to critical extent was Greece. The ability of Greek government to manage the crisis without sovereign default was doubted and the external aid in the form of unprecedented financial support in the form of loan facility from other Eurozone countries was provided in the hope of stopping the crisis from spreading to other Eurozone member states. In the thesis we study the Greek government debt crisis, its causes and also its evolution. As the main goal we try to estimate the evolution of the probability of default of the Greek government during the crisis using the information from the sovereign bond market.

The first chapter can also be called as a historical part of the thesis. We focus mainly on describing the both economic and political evolution of the crisis in recent years, from 2009 to April 2011, when the thesis was finished. But we also try to go into more distant history and we find the roots of the crisis in 1970s, so we show that the crisis was not caused by the accession of Greece to the EEC or to the Eurozone, but that it had much deeper and more country-specific causes. The last part of the first chapter studies the specific problems of Greek economy, which are shadow economy, tax evasion and high unemployment rate.

In the second chapter we introduce the methodology of using bond market information for evaluation of probability of default of Greek government. We show the main advantages of the bond-based models for the case of Greek debt crisis. Then we study the theory of probability of default. Finally we describe the theoretical background behind the chosen method of using bond market information for estimation of probability of default, which is the parsimonious method based on estimation of instantaneous forward credit spread curve of Greek government bonds using Nelson-Siegel based approach of estimating zero coupon bond yield curves from coupon bond data.

In the third chapter we show the alternative approach to the estimation of credit risk of government using the credit default swap contract information. At first we describe the CDS as an instrument. Then we show how to calculate the fair value of the CDS premium, which leads us to the estimation of the recovery value, which is used as a mean of credit risk valuation.

In the fourth chapter we apply the methodology shown in the second chapter in the case study of Greek government default risk. We estimate the daily evolution of the hazard function of the Greek government during the period of last two years and then we test the evolution of hazard rate through this period using several time series methods, including tests for structural breaks. Then we summarize our findings and we also discuss the drawbacks of the chosen method which were detected when it was used in practice.

Literature review

We will introduce the literature which was used in the thesis here. We will focus on the contribution of chosen literature to this thesis.

The **historical part** of the thesis is based on several works studying the economic history of Greece or its economy itself, on official EU documents and also on news from reliable online newspaper publishers, such as Guardian and Reuters. The news showed to be a very convenient and good source of information as they provided up-to-date information about so very quickly evolving topic as the Greek fiscal crisis is.

Alogoskoufis (1995) was an important source of Greek modern economic history. He studies the evolution of Greek institutional framework along with the economic performance. He pinpoints the most important events in Greek modern history from the political point of view also. He also deeply analyses evolution of main macroeconomic indicators of Greece from 1957 to 1992 and shows that there was a change in nature of Greek economy in 1974 and shows why.

Matsaganis and Flevotomou (January 2010) study the tax evasion in Greece and find that tax evasion is an important problem in Greece which causes redistribution of income. They found that the richest people in Greece do evade taxes most, so the tax progressivity is reduced and, in addition, when Greek government collects fewer taxes due to tax evasion, taxes have to be higher than without evasion. They also provide us with valuable estimates of tax evasion by level of income.

McGee and Tyler (October 2006) show an interesting study on tax evasion from the ethical point of view, which is relatively scarce in literature. The study presents the attitude of taxpayers in 33 countries, Greece among them, on the ethics of tax evasion. From the study we were able to see that Greece is ranked as a country where the tax evasion is not rejected much.

Schneider and Enste (1999) aim at estimation of sizes of shadow economies of 76 countries all over the world, including Greece, and show us also the methodology of the estimation. They also discuss the shadow economy, its definition and how it affects the economy.

Schneider (September 2010) focuses more at the recent world economic crisis and its impact on the size of shadow economies of Germany, Greece and other 19 OECD countries. He finds that Greece has the biggest share of shadow economy of all OECD countries.

The most helpful for the **theoretical part** of the thesis was Andritzky (2006). He study sovereign defaults in various countries and then he focuses on the estimation of probability of default of governments. He uses bond market information for that estimation and provides us with much theoretical concepts which can be used for it. After application of several presented methods in empirical studies of several countries, he also shows an alternative method for estimation of probability of default, which is exploiting information from CDS contracts.

Byström and Kwon (2005) study the bond market and provide us with a market-based approach to the estimation of their probability of default. They use this method for estimation of creditworthiness of firms. They see several advantages of the market-based approaches over the traditional credit rating methods. At first, we can estimate the entire "term structure" of default probabilities. We also do not rely on any historical values, possibly bad or outdated, we use only current market information. It is also not vulnerable to any data manipulation, feature required for the case of Greece.

Nelson and Siegel (1987) is a famous work on construction of parsimonious model of the yield curve. They try to find a model which would be simple and flexible enough at the same time. They succeeded in finding a model which fitted US Treasury bill yield curves well, allowing three basic shapes: monotonic, humped and S – shaped. We will use this model in the empirical part of the thesis.

Ferstl and Hayden (2010) provided us with a very practical paper which presents us the usage of the package called termstrc in software R for estimation of zero coupon bond yield curves using both coupon and zero-coupon bonds data. The paper not only shows the practical implementation of the package, but also reviews the needed theoretical background.

Baltagi (2008) is an econometrical textbook covering many areas of econometrics. It is the very useful resource of various econometrical methods needed for the testing of hypotheses in this thesis, mainly for the methodology of the Chow's test for regression stability.

1. Greek fiscal crisis of 2010

In the end of 2009 and especially in the beginning of 2010 media started to discuss worrying debt situation of Greece. Problems with Greek fiscal policy did not appear without causes and not so suddenly as it could have seemed. Even though the interest of media and public in worsening fiscal situation of Greece rose dramatically as late as from the beginning of 2010, the conditions for crisis developed continuously during many years before and the 2010 crisis is just the tip of the iceberg. We will discuss why the crisis appeared from a broader perspective. We will also see what is so worrying about situation in Greece, so we will be able to better understand why there have appeared doubts about solvency of Greece and thus why investors saw higher risk of default of Greek government. We will at first show the chronological evolvement of the Greek fiscal crisis from its origins in 1970s, then we will focus much more carefully on the latest development of the situation and then we will focus on tracking the reasons why the crisis happened recently from a broader perspective.

1.1. The foundations of the crisis

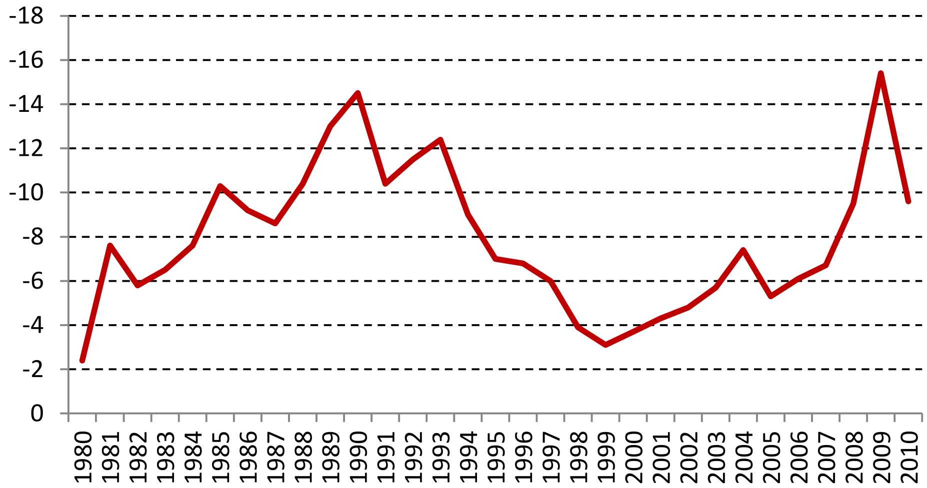
The history of the crisis of 2010 goes back as far as to 1970s, a way back before Greece entered the EEC and Eurozone. We will thus see that it is irrelevant to claim that the entry of Greece to EEC or Eurozone itself caused the crisis as it is from time to time claimed by some people. As the primary source for economic history of Greece in this period we will use Alogoskoufis (1995). In 1974, after a period of seven years of military dictatorship, a democratic regime was restored. Until then the role of state in the economy was not very important, except for public administration, banking, electricity and telecommunication sectors. The economic regime of dictatorship was almost the same as in 1950s and 1960s and Greece saw a period of prosperity backed by low business taxes, high investments, protection of property rights etc., which created a good environment for growth. However, in 1973, after the collapse of Breton Woods system and the rise in commodity prices, heavy inflationary shock hit Greece. Greece was his so severely because of the carried repressed inflationary pressures from 1969 onward when the economy almost reached its full capacity, but administrative controls did not allow wages and prices to accommodate. The severe crisis in 1973 led to the political crisis of the dictatorship and to its fall in 1974.

After 1974 deep changes in economy started to happen under the Konstantinos Karamanlis, founder of the New Democracy party. There was a dollar peg regime before which was abandoned for a crawling peg regime. The monetary policy became very lax, together with the fiscal policy. Some populist steps were taken, such as increased redistribution, also the defense expenditures were expanded quickly. Even though the labor unions had just little power before, they became very powerful now. Together with extensive price controls the real wages were increased steeply, but accompanied with increased government expenditures and increased business taxes, which were low before. The property rights were endangered and the role of the state in the economy was increased by much nationalization, such as nationalization of the second largest banking group. In 1981 Greece entered the EEC and this year also saw PASOK (Panhellenic Socialist Movement) win the parliamentary elections and Andreas Papandreou became the prime minister of Greece.

The role of state was strengthened even more with more nationalizations and income redistribution, together with widened price controls and wage indexation. The government debt started to boom and Greece also had to face a balance of payments crises in 1985 and 1989/1990. In 1990 Konstantinos Mitsotakis of New Democracy became the prime minister and in 1992, the third Minister on National Economy, Stephanos Manos, tried for the first time to take an action to fight the deficit. Measures to liberalize prices, to deregulate state enterprises, to reform social security system, to run privatization of state enterprises and to increase infrastructure investment were taken. However, in 1993, after new elections, PASOK won the elections and Andreas Papandreou became the Prime Minister. Fiscal reforms were reversed or abandoned and no further steps were taken to fight the deficit.

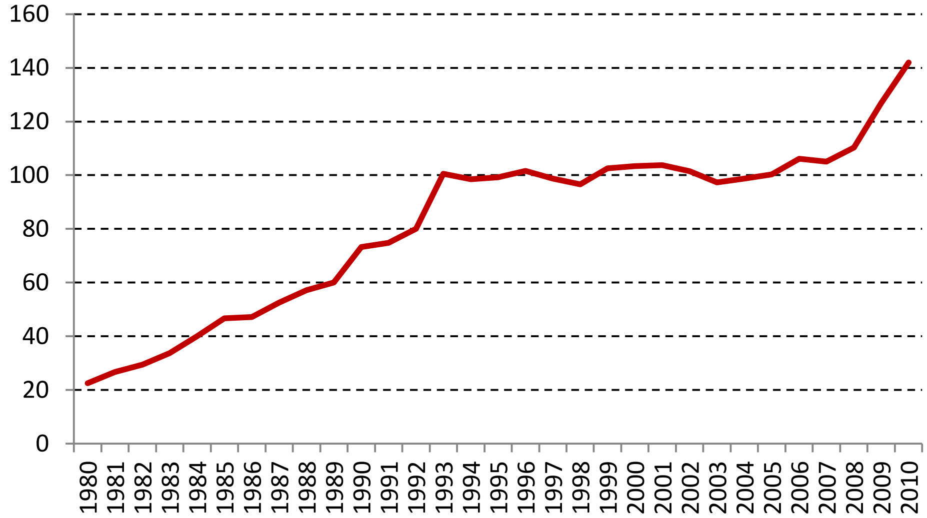
We can now study several graphs depicting the evolution of Greek economy from 1980 until 2010. Following graphs show the evolution of government deficit during this period together with the total government debt.

Figure 1: Greek government net lending/borrowing (% of GDP)



Source: IMF Data Mapper. Accessed 18 April 2011

Figure 2: Greek government gross debt (% of GDP)



Source: IMF Data Mapper. Accessed 18 April 2011

We can see that even though in the beginning of 1980s the total volume of the debt was still relatively low, it quickly ballooned to values breaching 100 % of GDP. We can see that the debt was being built until 1993, and then it became conserved at levels around 100 % of GDP.

1.2. History of the crisis of 2010

We will now show how the crisis of 2010 itself evolved chronologically as it will be an important part for establishing hypotheses for empirical part of the thesis. We will mainly focus on the relation between Greece and the European institutions in the first part as in that time there was not much attention paid to the Greek situation, but from certain point we have much information from news. We will use the most reliable for our purpose to see the crisis not only from the perspective of the Greece – EU official relations.

1.2.1. The Greek excessive deficit procedure

Even though the Greek fiscal crisis broke out in 2010 to the full extend, we should go back to the 2009 if we want to follow it from its beginning. We will follow mainly the EDP of Greece which we will see will be very helpful if we want to find the trigger point of the crisis itself.

On 18 February 2009 the European Commission made a report (Commission Report 2009/197/SEC) showing a bad state of Greek deficit and its total debt. It is a report prepared for The Council in cases that there is a suspicion that a country of the EU should enter so called EDP. According to the legislation which was in force, there were two conditions for a country to enter the regime of EDP:

"(a) whether the ratio of the planned or actual government deficit to gross domestic product exceeds a reference value, unless:

- either the ratio has declined substantially and continuously and reached a level that comes close to the reference value,
- or, alternatively, the excess over the reference value is only exceptional and temporary and the ratio remains close to the reference value;

(b) whether the ratio of government debt to gross domestic product exceeds a reference value, unless the ratio is sufficiently diminishing and approaching the reference value at a satisfactory pace." (OJ C 325, 24/12/2002, Article 104)

The Treaty of Lisbon, which entered into force 31 December 2009, adopted legislation concerning EDP from TEC with only changes concerning procedure itself, not the conditions which decide whether EDP should be started for a country (OJ C 306, 17/12/2007, Article 126). Therefore we know that the rule of entering EDP didn't change. The two reference values which the rule refers to are 3 % for the government deficit and 60 % for the ratio of government debt to gross domestic product and did not change by the Treaty of Lisbon (OJ C 321 E, 29/12/2006, Protocol No 20 and OJ C 115, 09/05/2008, Protocol No 12).

The report from the Commission mentioned before (Commission Report 2009/197/SEC) concluded that both criteria were breached, because government deficit reached 3.5 % in 2007 and debt to GDP ratio stood at 94.8 %. Report stated that deficit cannot be seen as temporary nor exceptional, because "fiscal imbalances have been high and persistent for many years, in spite of the buoyant economic activity up to 2008, and have structural roots" (Commission Report 2009/197/SEC, p. 2). It also stated that "the debt ratio cannot be considered as diminishing sufficiently and approaching the reference value at a satisfactory pace" (Commission Report 2009/197/SEC, p. 11).

Next step in the procedure was done on 24 March 2009 when three documents were created by the Commission. At first, Commission published its opinion on Greek deficit based on its previous report from February. It came to the result that "the Commission, having taken into account its report and the opinion of the Economic and Financial Committee, is of the opinion that an excessive deficit exists in Greece." (Commission Opinion 2009/563/SEC, p. 6) The second step was that the Commission recommended the Council of the European Union (further just Council) to adopt a decision which would agree that there is an excessive deficit in Greece (Commission Recommendation 2009/564/SEC). The last document was a recommendation of the Commission to the Council which would recommend Greece to end the excessive deficit situation (Commission Recommendation 2009/565/SEC).

As the Commission recommended the Council decided that an "excessive deficit exists in Greece" (OJ L 135, 30/05/2009, p. 22) on 27 April 2009 and it also recommended Greece to end excessive government deficit situation on the same day (Council Recommendation 2009/7900/09/CR).

On 11 November 2009 the crucial document was released by the Commission (Commission Recommendation 2009/1549/SEC). It can be considered the trigger point of the crisis. In the empirical part of the thesis the hypothesis whether 11 November the crisis started will be tested. This Commission recommendation for a Council decision "establishing whether effective action has been taken by Greece in response to the Council recommendation of 27 April 2009" included several important facts about evolution of Greek situation relevant for fiscal sustainability of Greek economy. At first this decision concluded that "Greece has not taken effective action in response to the Council Recommendation of 27 April 2009 within the period laid down in that Recommendation" (Commission Recommendation 2009/1549/SEC, p. 13). It means that Greece did not try hard enough to end its excessive deficit, which was a bad signal. But the key information mentioned in the document relevant for beginning of the crisis was that Greek data concerning the deficit had to be revised substantially. The table no. 1 shows the evolution of the Greek deficit estimates until 11 November 2009 as they were published in various documents.

Table 1: The evolution of estimates of Greek government deficit and GDP growth until 11/11/2009 (in % of GDP and in % respectively)

	GDP growth			Government deficit		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**
Budget 2009	3.2	2.7	N/A	2.5	2.0	:
Commission 2009 January	2.9	0.2	0.7	3.4	3.7	4.2
Stability Program 2009 January	3.0	1.1	1.6	3.7	3.7	3.2
EDP notification 2009 April	:	:	:	5.0	3.7	:
Commission 2009 Spring	2.9	-0.9	0.1	5.0	5.1	5.7
EDP notification 2009 October	:	:	:	7.7	12.5	:
Commission 2009 Autumn	2.0	-1.1	-0.3	7.7	12.7	12.2

Source: Commission Recommendation 2009/1549/SEC

We can clearly see that all estimates were worsening over time. But the most important change was the estimate of 2009 deficit by EDP notification from 21 October 2009 (Eurostat, 21/10/2009). The deficit was revised to be more than twice the estimate from previous, Commission, estimate and it was now by 10.5 pp higher than was the Greek 2009 budget plan. In addition to this revision, Commission Recommendation from 11 November 2009 also increased the estimate of 2010 government deficit substantially to 12.2 % and newly concluded the poor effort done by the government to cope with the budget which together was important information for public which started to worry about bad fiscal situation in Greece from this moment on. This decision was later really adopted by the Council on 19 January 2010 (OJ L 125, 21/05/2010).

1.2.2. Worsening of the situation and introduction of reforms

From this moment on the situation of Greece was rapidly deteriorating and it was more and more sure that it will become unbearable and Greece will have to ask for external aid. However many actions were taken to try to avoid the worst. The interest of public and media in Greece started to grow. Rating agencies, responsible, among others, for estimation of credit risk of governments started to worry about the Greek government's creditworthiness. The Fitch rating agency downgraded Greek rating from A- to BBB+ on 8 December 2009 with negative medium term outlook (Smith and Seager, 8 December 2009).

The Greek politicians tried to calm down the situation, namely George Papandreou, newly elected Prime Minister of Hellenic Republic after Greek elections on 6 October 2009 (Smith, 6 October 2009) promised to run an intensive overhaul of Greek economy to improve its public debt in a speech given on 14 December 2009 (Smith, 14 December 2009). In his speech he proclaimed that his program would reduce fiscal deficit to 3 % by the 2013 when his election period ends. His plans were to cut off expenditures by lowering government operating expenditures, consumption costs and by contracting the big public sector.

The Greek stability and growth program was presented by Greek finance ministry on 14 January 2010 (Reuters, 14 January 2010). Its main goal was to reduce large budget deficit. The growth of Greek economy was to be driven by development of areas where the Greece had comparative advantage. Deficit was projected to decline gradually and the debt would peak, according to the predictions, in 2011 at 120.6 % and would slowly shrink thereafter at pace of several percentage points per year. Expenditures were to decline from 52 % of GDP in 2009 to 47.7 % of GDP in 2013 and revenues were expected to increase from 39.3 % of GDP in 2009 to 45.7 % in 2013. These goals were backed by many intended reforms and changes in fiscal strategy addressing many flaws of Greek economy. Government committed to restoration of trust in government statistical services by ensuring more independence of National Statistics Service. The important step was also to reform tax system in order to simplify it and also to improve its vulnerability to tax evasion by auditing enhancement. Great attention was paid to expenditure reforms which were to reduce government spending. A contingency reserve was to be created from 10 % of budgetary appropriations to create a budgetary pillow for 2010. In addition salaries exceeding EUR 2000 monthly in the public sector were intended to be cut by 10 % and frozen during 2010 and no employees were to be hired to replace retired public sector employees in 2010 and the replacement was to be done in 5:1 ration from 2011. Also operating expenditures of ministries were to be cut by 10 % in 2010. Also some long run plans were shown among those the most notable were reforms of health care expenditures and pension system.

The EU, however, addressed Greek government officially to improve Greek budget deficit, so the Council posted a decision with steps which should be done in Greece to end the excessive deficit procedure to Hellenic Republic on 16 February 2010 (OJ L 83/13, 30/03/2010). The deadline of the year 2012 was given to end the excessive deficit. The Council stressed that there were specific steps to be done in order to run fiscal consolidation in line with the Greek stability and growth program mainly. The measures are divided into three types: A. measures to be taken by 15 May 2010, B. supporting measures and finally C. measures to be taken by the end of 2010. The measures are divided further to expenditure, revenue and fiscal framework types. There are also strict deadlines for reporting on progress of reforms. The proposed steps are in many features similar to Greek stability and growth plan.

The expenditure side steps to be taken by 15 May 2010 were to move 10 % budgetary appropriations of government's departments intended to be used in 2010 for use when the good use of them would be rationalized later, then the wages were to be frozen, recruitment stopped (even replacement of retired permanent officials) and vacancies canceled in government sector in 2010. Also the cuts in special allowances paid to civil servants were to be cut. The document also proposes cuts in transfers by the social security not specifying any precise numbers. The short term revenue side actions include implementation of progressive tax scale for all types of income and also not differing between labor and capital income. To try to fight against tax evasion, the presumptive taxation was to be introduced for self-employed. Also all tax exemptions were to be cancelled in the tax system. Also other tax-gains-increasing measures were to be introduced, as increase in tobacco, alcohol and fuel excise duties and also an introduction of permanent levies on buildings and overall increase in real estate tax rates.

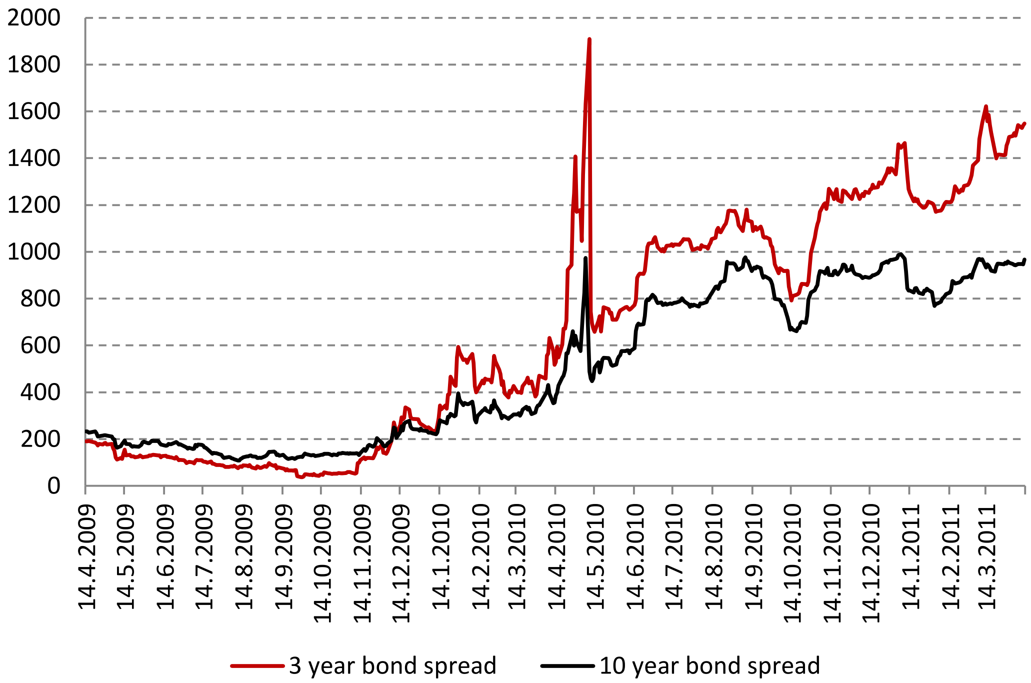
Next part lists measures to be adopted by the end of 2010. On the expenditure side of budgetary measures there is the rule of 5:1 retired public sector employees replacement rate introduced as it was by the Greek stability and growth program. Also the pension and healthcare system reforms are to be done to bring lowered expenditures, for example using increasing the retirement age, lower upper limit of pensions. Finally the wage bill is to be lowered by reform of the wage payment system. The revenue measures to be taken by the end of 2010 are the increased endeavor in the fight against tax evasion and fraud, which are two very burning issues in Greece as it will be shown in the chapter 1.2., by amelioration of legal enforcement of tax payments. The material also stress that all potential gains are to be used for deficit reduction. Also the tax collection administration is to be enhanced by establishing of tax collection department. There is also part devoted to the fiscal framework enhancement pinpointing some additional measures to be taken in order to improve the fiscal position of Greece, such as the fight against corruption in public administration, setting spending ceilings, avoiding reduction in average maturity of public debt (obviously due to fears that increasing interest rates would cause low-maturity debts to renew at higher rates more quickly than long-maturity debts, thus increasing the deficit), etc.

There are also fiscal measures to be adopted by 2012. On the expenditure side, need for permanent savings by lowering government consumption is stressed by further reduction of wage bill and social transfers accompanied by lower number of public employees. On the revenue side, just a continued effort in the reform of tax administration is mentioned. The Greece should also further improve its fiscal framework and, which is very important, try to improve its general government data collection mechanisms.

1.2.3. The need for an aid package

Meanwhile the debates across the EU started about the possible aid which could be provided to Greece. On 28 January 2010 George Papandreou said Greece would solve its problems on its own and that he did not ask about any bilateral loans with Germany or France (Elliott, 28 January 2010). It was, however, very bold claim, because the possibilities of raising debt regularly through the market dramatically worsened as the interest rates were climbing quickly. The closing yield till maturity of 10-year Greek government bond was 7.059259 % on 28 January 2010 (Reuters Wealth Manager). The increasing interest rates on government bonds, which were the primary element of government debt, increased also the cost of governmental borrowing, so Greece stood, with its great deficits and rising costs of borrowing, on the edge of vicious circle. Borrowing at higher rates lead to increased expenditures and to the need of bigger loans to cover larger deficit, thus decreasing its creditworthiness and increasing interest rates further. In analyses made later they realized that Greece needed to raise new debts worth approximately EUR 53 billion just to service its debt until the end of the year (Smith, 4 March 2010). We can also demonstrate the severity of the situation looking at the evolution of spread of Greek 10 year bonds over German 10 year bonds during and also before the crisis to compare it. 10 year maturities are commonly used for reference. You can also see a comparison of a short-term 3 year bond yield and spread in the following picture to see that the yield curve exercised a reversed shape typical in crisis. The spreads of 3 year bonds rose to values near 2,000 basis points in the worst period of the crisis, which is a very rare value for government bonds.

Figure 3: Greek 3 and 10 year government bond spread over German government bonds (in basis points)



Source: Reuter's Wealth Manager. Accessed 14 April 2011

In the beginning of 2010 there was no interest of Greek government in any support from EU as Papandreou said on 28 January 2010 (Elliott, 28 January 2010). Greek government wanted to try to solve the situation domestically. Some negotiations were done about the possible aid from the EU (Traynor, 9 February 2010), but especially Germany did not want to do such a bailout. Angela Merkel, Chancellor of Germany, said that Greece did not ask for any support and “repeatedly emphasised that Athens would need to put its own house in order and brushed aside all questions of financial support” (Traynor, 11 February 2010).

The situation evolved very quickly as already during the March 2010 the negotiations were renewed and Germany did agree with other 15 Eurozone members and IMF on the very first version of rescue package for Greece on 25 March 2010 (Traynor, 26 March 2010). It was negotiated that a package will be ready if Greece will need it as a possibility of last resort. Some concrete terms, however, were not negotiated yet. Angela Merkel also conditioned the help by introduction of new stricter rules for countries which will endanger Euro currency by its bad fiscal discipline. It is an important note to say that the Greek fiscal crisis caused serious problems for the whole Eurozone as the future of the whole Euro currency was challenged in opinion of many (see chapter 1.3. for further discussion of this issue).

On 11 April 2010 the conditions of Greek rescue package got a concrete form (Wray, 11 April 2010). It should have a form of EUR 30 billion debt pegged at 5 % interest rate, which was main advantage of the package for Greece, because the closing yield of 10 year Greek government bonds was 7.195153 % on Friday 9 April 2010 (Reuters Wealth Manager). The important legal feature was that "if the mechanism had to be activated, it would not be a violation of the no-bailout clause (in the European Union treaty) since the loans are repayable and contain no element of subsidy," said Jean-Claude Juncker, the Luxembourgian prime minister and the president of Eurogroup (Wray, 11 April 2010). The whole amount of EUR 30 billion was to be provided by all Eurozone members proportional to their share in ECB’s capital. IMF was to provide additional loan of approximately EUR 15 billion. Papandreou still did not ask for the package to be activated and he still hoped in the ability of Greece to borrow through the market.

Nevertheless, four days later Greek economics minister has officially asked IMF and EU to discuss the specific conditions of aid package. “’Markets have no patience – when they cut you off, they cut you off. It's a matter of trust between the borrower and the lender, and Greece has done things wrongly in the past,’ an official close to the Greek government said.” (Moya, 15 April 2010) By this moment, markets became really impatient in upcoming days and more and more seeing the possible default of

Greece as an existing threat. On 15 April 2010 the closing yield of Greek government bonds was 7.182477 % (Reuters Wealth Manager). Several days later, on 23 April 2010, Greece activated the financial aid package from IMF and EU as the austerity measures did not avert the fear of bankruptcy and the cost of borrowing through the market steadily rose (Smith, 23 April 2010). The 10 year government bonds stood at new peaks closing at 8,823047 % on 22 April 2010 (Reuters Wealth Manager), day before the activation of the aid, so the EUR 16 billion of debt maturing in May, were quickly becoming too expensive to refinance.

The German part of the help was, however, froze until Greece would enact stricter austerity measures from the IMF, which were longer and more radical than those from the EU. German part of the package amounted EUR 8.4 billion (Traynor, 26 April 2010). Market yields of Greek government bonds continued to rise quickly in the light of these events together with the news that Standard & Poor's rating agency downgraded Greek government bonds to the first non-investment, so called "junk" status on 27 April 2010 (Wachman and Fletcher, 27 April 2010). Day after the non-investment grade was assigned to Greek government bonds, the yields of 10 year bonds peaked at the day high of 12.588 % (Reuters Wealth Manager). One of the main reasons for a downgrade may have been that the rescue package was not, by many experts, large enough. Erik Nielsen of Goldman Sachs said that it should have been at least EUR 150 billion over next 3 years and Steven Major, head of fixed income research at HSBC, said it should have been at least EUR 110 billion over next 2 years (Wachman and Fletcher, 27 April 2010).

1.2.4. Expansions of the aid package in the light of worries about debt contagion

While the first aid package seemed to be insufficient, which was proved by the steep increase of yields on Greek government bonds showing the fear of investors, the package was quickly expanded. There were new terms of the aid package negotiated on 2 May 2010 (Traynor, 2 May 2010). The package now consisted of EUR 110 billion distributed into 3 year period. The Eurozone members contributed EUR 80 billion and IMF contributed EUR 30 billion to the package. It was also conditioned on quarterly monitoring of progress of implementation of Greek austerity measures. The international aid in this amount had never been realized before. '"This programme is unprecedented … in the scale of the financial support," Olli Rehn, European commissioner for monetary affairs, said last night.' (Traynor, 2 May 2010) However it seemed there were no other choices if the Greece should be saved and the Euro currency as well. "José Manuel Barroso, head of the European commission, described the bailout as decisive in preserving 'the stability of the euro area'." (Traynor, 2 May 2010).

The markets, however, did not react to this news positively and the Greek government bond yields continued to rise. Many started to claim that even this bigger aid will not be sufficient for Greek recovery (Wearden, 4 May 2010). According to Elliott (4 May 2010), for example, the aid for Greece had features which made the situation even worse. He says that if Greece was not a part of Eurozone, IMF would suggest Greece to help its export by devaluation of currency and reduce interest rates to offset the fiscal tightening of austerity measures. However he says that it cannot be done, because Greece is in the monetary union and cannot control its monetary policy. He then worried about the future of Greece, because the inability to support growth via exports, combined with drastic austerity measures damaging the aggregate demand, would lead to the "economic death spiral".

As also in other countries debt crises had developed, such as in Spain, Portugal or Ireland, crisis of Eurozone and the whole European Union arose. There were fears about the future of the Euro currency mainly. Wachman and Allen (9 May 2010) provided a helpful overview of opinions of several experts on the crisis of Eurozone. We will mention them briefly. Richard Lambert, Director-General of the Confederation of British Industry, said Euro currency was "more a political project than economic one" and thought that its end would be "potentially disastrous" for member states, because it would also mean increased political and economic uncertainty. Gerard Lyons, Chief economist at Standard Chartered, believed that Euro was not sustainable in its current form. He said that history showed that without a political union there had never survived any monetary union of large nations. He said that the one interest rate did not suit all countries and thus that Eurozone was not optimal currency area. Anton Börner, President of BGA, the Federation of German Wholesale and Foreign Trade, wanted Euro to survive this crisis much. He defended Euro as very beneficial for all Eurozone member states, especially for their export-dependent companies. He said that no need for currency hedging and exchange fees saved much money for them saving jobs as well. He also mentioned that no volatility of exchange rates in Eurozone also made long-term planning easier. John Fitzgerald, Economist at Economic Social Research Institute, Dublin, did not foresee a collapse of Eurozone. He admitted that the Greek rescue package “raised expectations that other countries with problems can rely on outside help”. However he believed that other countries in crises, such as Spain, would be able to solve their problems. Lord Jay of Ewelme, Vice-chair of Business for New Europe, said that the “crisis was not caused by the markets – it was caused by governments spending beyond their means. They have been in denial about rising debt and the need for economic reform.” He believed that after the crisis the Euro would help countries to grow. Dylan Grice, Global markets strategist at Société Générale, was not sure whether the Euro would have collapsed, but he warned all indebted governments to pay attention to the market which could behave unexpectedly.

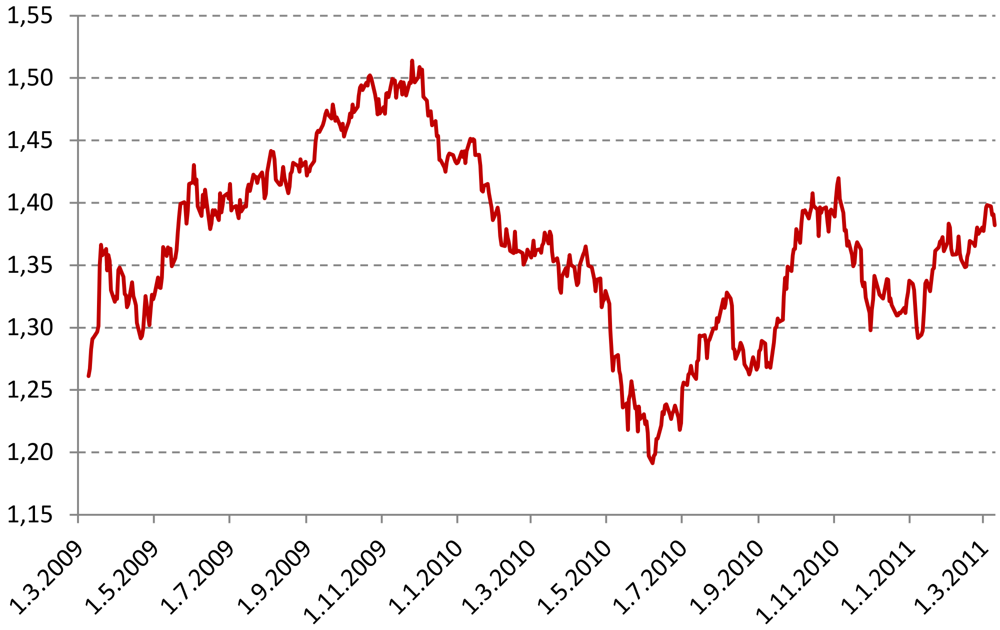
The fear of contagion of the debt crisis through several other Eurozone countries with debt difficulties and effort to stabilize markets led to the decision to establish an unprecedentedly large package for debt crisis stricken countries on 10 May 2010 (Elliott, 10 May 2010). The total amount of aid was EUR 750 billion, of which EUR 60 billion were intended to be loans for countries with imminent debt problems, other EUR 440 billion were in the form of loan guarantees from the EU and another EUR 250 billion from the IMF.

The fears about Eurozone future lead to take further steps in Germany, which banned short selling of stocks of 10 biggest German financial institutions, but also of sovereign bonds of Eurozone members and CDS on them. The ban was to be in effect until 31 March 2011 and it only covered trading via BaFin, financial regulatory authority of Germany (Wearden, 19 May 2010). It was a step to try to fight against speculative trades with named instruments.

1.2.5. Further development

Further development of the situation until recently can be described briefly as a very turbulent period. The fear of contagion was extended to Hungary on 4 July 2010 as it was revealed that Hungarian former government falsified data on Hungarian government debt, according to Hungarian prime minister’s spokesman, and Euro currency reacted to this news by a drop in value to a four-year minimum (Reuters, 4 June 2010). The whole turmoil in the EU about the debt crisis in Greece and also in several other countries together with speculations about the unsure future of the Euro currency harmed value of Euro as we can see in the graph below. Euro was on a downtrend approximately from November 2009 to June 2010.

Figure 4: USD/EUR exchange rate (in USD per 1 EUR)



Source: Reuters Wealth Manager. Accessed 10 March 2011

While the Greek government tried to fight against its debt, painful fiscal restrictions had already caused many demonstrations and strikes in Greece. The tensions escalated during the summer holidays of 2010, when Greek truck drivers were on strike for six days. The strike had paralyzed whole economy as there were shortages of petrol supply, for example. Petrol had to be distributed using military vehicles to ensure it at least for airports, hospitals and power stations (Smith, 1 August 2010). A guerrilla group Sect of Revolutionaries exploited the situation and said via declaration: “We intend to turn it (Greece) into a war zone of revolutionary activity with arson, sabotage, violent demonstrations, bombings and assassinations, and not a country that is a destination for holidays and pleasure.” (Smith, 3 August 2010)

Meanwhile, however, several positive events also happened from perspective of the Greek government. The statement of a monitoring visit of Greece by the EU, IMF and ECB concluded that the Greek government made a strong progress and implemented reforms even ahead of schedule, which was followed by allowance of drawing another funds, EUR 9 billion, from the aid package (Moya, 5 August 2010).

However the statement also concluded that it is important to improve efforts in tax collection. It was reflected in the speech by George Papandreou on 20 October 2010 who pronounced that “there will be no additional burden placed on wage earners and pensioners” (Smith, 20 October 2010) and instead he wanted to fight against tax evasion. Over 1 million tax evaders were offered an amnesty for 10 years back. Yannis Kapeleris, the head of the financial crimes unit, said his goal was to collect penalties EUR 5 billion in 2010 (Smith, 20 October 2010).

Later, in December 2010 Eurostat estimated that the public debt will continue to grow rapidly in Greece reaching 160 % of GDP in 2013 and the prediction of unemployment rate for 2011 was also worrisome 15 % accompanied by the estimate that 2 million Greeks lived below poverty line and more than 25 thousand businesses had been closed since May 2010 (Smith, 6 December 2010).

During the crisis also several controversial suggestions were presented by the creditors of Greek government to fight against its debt also by privatization of various national properties, such as many tourist attractions, beaches, ports, airports etc. International auditors proposed privatizations worth approximately EUR 50 billion. Papandreou said, however, that such privatizations would not be considered (Smith, 17 February 2011). Approximately one month later Papandreou succeeded in negotiation of better terms of repaying the aid package. The interest rate was reduced by 1 p.p. and the repayment period was also prolonged to seven and half years, almost doubling the original length of the loan. However, speculations that better terms were allowed thanks to the agreement to the controversial EUR 50 billion privatization program arose (Smith, 13 March 2011).

By the time this thesis was finished the Greek government had not defaulted, but the speculations were rising about the restructuring of Greek debt being inevitable solution. Greek families, for example, would welcome it because of the painful fiscal restrictions which would not be necessary in the whole extend if the debt was restructured. There are estimates saying that the disposable income of an average family was reduced due to austerity measures by 40 % (Smith, 13 April 2011). However, restructuring would also harm Greek creditors, such as banks or pension funds and would destroy Greek’s creditworthiness much making it impossible to borrow from capital markets again for a long time, so George Papandreou insist the reforms are the right solution and rejects any speculations on Greek default (Smith, 13 April 2011). We will probably see in the near future if the reforms will stabilize the situation in Greece which is not sure at all nowadays. As far as the Greek aid package is concerned, we can conclude this chapter by the table of disbursements done by the EU and IMF so far to Greece as European Commission reports them.

Table 2: Disbursements of funds of Greek Loan Facility (in EUR billion)

Disbursements	Euro-area	IMF	Total
May 2010	14.5	5.5	20.0
Sept 2010	6.5	2.5	9.0
Dec 2010	--	2.5	2.5
Jan 2011	6.5	--	6.5
March 2011	10.9	--	10.9

Source: European Commission (2011)

1.3. Origins of the crisis of 2010

We will now study why the fiscal crisis broke out in Greece. We will try to tackle its real causes. There are several fields of interests we will have to search for our goal. We cannot cover all causes because of the complexity of the problem, but we can try to find the most important.

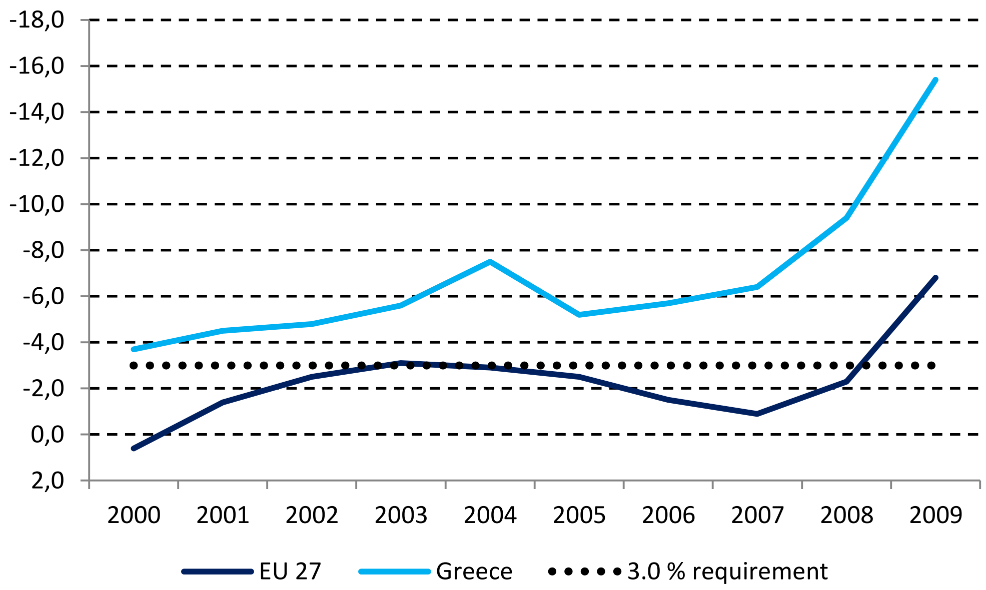
1.3.1. Role of the world financial crisis: just the last straw

What is very important is to remind that Greece, as most countries in the world, also struggle due to the global financial crisis. Someone could suggest that it is the main reason why the fiscal crisis arose in Greece. But even though there are many economies stricken with the crisis and many have some fiscal problems, in no other country of the EU neither total debt in percent of GDP nor government deficit in percent of GDP is as huge as in the case of Greece (see appendices 1 and 2). Also we saw in chapter 1.1. and we will see in chapter 1.3.3. that there are long-term causes of the fiscal crisis. The world financial crisis just pronounced those problems to extreme.

In appendix 1 and 2 you can see the comparison of evolution of government deficits and total debt amounts, all in percent of GDP, for all current EU countries. As we can see, most EU countries extended their debts and most EU countries also worsened their deficit during the world financial crisis (from 2007). Even though there are some countries with also worrying state of their public finance in the EU, situation of other countries of the EU is not as urgent as the crisis in Greece is despite of the world financial crisis. It means that the world financial crisis is not the only cause of the fiscal crisis in Greece. We will argue in other sections of this chapter that there are many other causes which were specific to the Greek economy. After realizing this, the world financial crisis can be seen more like something that unveiled the weaknesses of economy rather than something what caused the fiscal crisis itself.

We will now try to demonstrate the first simple insight into the idea that the fiscal crisis in Greece had structural roots and that the world financial crisis would not cause the fiscal crisis without these structural causes.

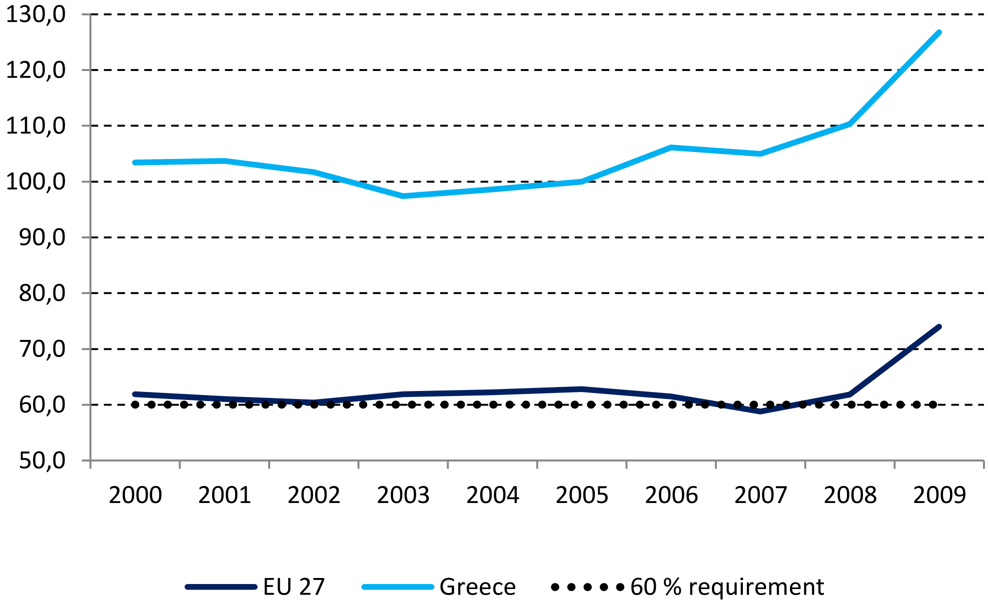
Figure 5: Government deficit (-)/surplus (+) in Greece and EU 27 (in % of GDP)



Source: Eurostat Statistics Database. Accessed 23 November 2010

If we inspect the figure above we can see an important finding: Greece has run its budget with substantially higher deficit than the average of EU 27 is for many years. Secondly, Greece has never met requirement of deficit under 3 % during the period under consideration, even after adoption of Euro in 2001. In contrast, this rule was breached by “average EU 27 country” importantly only during the world financial crisis.

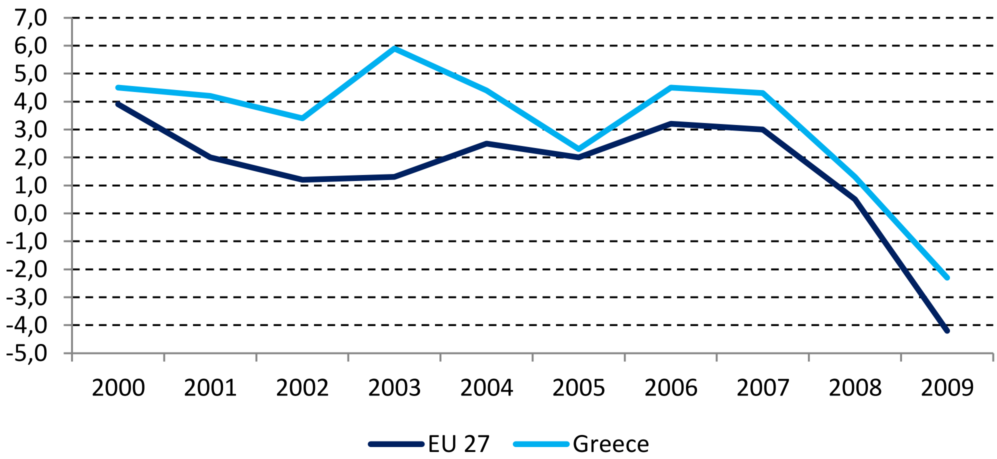
Figure 6: Total government debt (in % of GDP)



Source: Eurostat Statistics Database. Accessed 23 November 2010

The figure 6 shows that Greece never complied with 60 % debt to GDP ratio requirement during the selected period. What is even more important is that there is not even a downward trend in the ratio, but it just oscillated around 100 %, value to which the debt was built in 1980s as we saw in chapter 1.1., before the crisis and then it soared to 126.8 % in 2009. The average of EU 27 oscillated around the requirement value and went up during the crisis.

Figure 7: Growth of the real GDP in Greece and EU 27 (in %)



Source: Eurostat Statistics Database. Accessed 23 November 2010

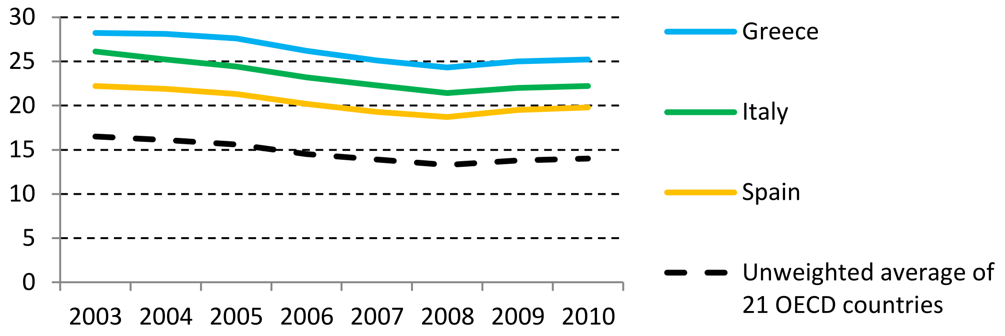
From the figure 7 we can see that Greece had substantially higher real GDP growth than the average of EU 27 during the selected period, especially before the world financial crisis. The average growth of real GDP of Greece between 2000 and 2007 is 4.2 %, while in EU 27 only 2.4 % (author's calculation based on appendix 3). It is important to mention that GDP growth values from 2004 until 2009 are still considered provisional by Eurostat. All other countries of EU 27 have all values considered as final in the selected period. Nevertheless even data from 2000 till 2003, which are considered final, show the presented evidence. You can also see the detailed table of all EU 27 countries' GDP growth values from 2000 till 2009 in appendix 3.

If we merge our findings about Greek real GDP growth and government deficit now, we can conclude that Greece before the world financial crisis experienced almost double real GDP growth than EU 27 and still it was running high deficits, much higher deficits than it was usual in the rest of the EU, not meeting the requirement of 3 % by far, not taking the advantage of high real GDP growth to reduce its very high indebtedness. The loose fiscal policy until the world financial crisis was then quickly turned into the fiscal crisis during the world financial crisis, in contrast to most EU countries whose fiscal policies were much more prudent before and were able to withstand deteriorated deficits. The world financial crisis did not cause the fiscal crisis in Greece on its own, because Greece had bad state of its fiscal policy even before, so it was not able to absorb the shock of the world financial crisis.

1.3.2. Shadow economy and tax evasion

One of the most important features of Greek economy from the point of view of the fiscal policy is the high share of shadow economy on total economy and high rate of tax evasion. It is not easy to define shadow economy as different authors use different definitions. It will be useful for this thesis to be consistent with the approach of Schneider and Enste (1999) who state: "In our analysis of the shadow economy we concentrate on legal value added creating activities, which are not taxed or registered and where the largest part of them can be classified as 'black' or clandestine labor."

Figure 8: Size of shadow economy in Greece, Italy, Spain and an unweighted average of 21 selected OECD countries[1] (in % of the GDP)



Note: values for 2010 are provisional

Source: Schneider (September 2010)

In the figure 8 we can see the evolution of the size of Greek shadow economy and its comparison to the unweighted average of the selected OECD countries (see footnote 1) expressed as a share of GDP, which means as a share of the official economy. We can clearly see that the Greek economy can be characterized by a big size of shadow economy. Even though there are countries with substantially bigger shadow economy in the world, those countries are not among developed countries. From OECD countries, Greece has the biggest shadow economy. The high share of shadow economy is typical for some other South-European countries also, as for Italy and Spain, for example. As Schneider (September 2010) states, the decline of the relative size of Greek shadow economy until 2008 was caused by growing official economy mainly. Then the shadow economy began to rise due to the world financial crisis to 25.0 % in 2009 and 25.2 % in 2010.

The reason why the sizable shadow economy is so harmful for Greek government fiscal policy is that activities in the shadow economy are not taxed. It means that there are shortfalls of tax collections due to shadow economy. On top of that there is also high tax evasion in the official economy in Greece contributing with additional tax shortfalls.

There are also studies concerning the tax evasion independently from the shadow economy. McGee and Tyler (2006) study the attitude of population in 33

[1] Selected 21 OECD countries are: Australia, Belgium, Canada, Denmark, Germany, Finland, France, Greece, United Kingdom, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Austria, Portugal, Sweden, Switzerland, Spain, U.S.A.

different countries (and regions)[2], including Greece. The used survey data are from 2004 by Inglehart. The paper shows interesting findings about the survey which asked people whether tax evasion is justifiable[3]. From 33 countries Greeks were on the 32nd place if we rank the countries from the most opposing to the most agreeing with the tax evasion. Only 37 % of Greeks told that tax evasion is never justifiable. The average survey rate from all 33 countries was 54.9 %. To compare with the other South-European countries, the rate was 57 % in Italy, 55 % in Portugal and 57 % in Spain. We can see that the tax evasion approval in Greece is Greece specific in the Southern Europe unlike the shadow economy.

Matsaganis and Flevotomou (January 2010) try to directly estimate the share of unreported taxable income and also the amount of tax shortfalls due to the tax evasion. The table 3 shows the rate of under-reporting of taxable income in 2004/05 by level of income.

Table 3: Rate of under-reporting of income (in EUR per person per year)

Income group	Survey income	Tax reported income	Difference
Decile 1 (poorest)	1,963	1,769	-9.9%
Decile 2	3,540	3,174	-10.4%
Decile 3	5,667	5,031	-11.2%
Decile 4	7,079	6,715	-5.1%
Decile 5	8,191	7,723	-5.7%
Decile 6	9,867	9,172	-7.0%
Decile 7	12,298	11,322	-7.9%
Decile 8	15,447	14,314	-7.3%
Decile 9	19,869	18,525	-6.8%
Decile 10 (richest)	39,650	33,839	-14.7%
Top 1%	96,526	73,732	-23.6%
Top 0.1%	156,859	126,523	-19.3%
Total	12,455	11,220	-9.9%

Source: Matsaganis and Flevotomou (January 2010)

[2] Data are taken from a survey in Austria, Belarus, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany (East), Germany (West), Great Britain, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Northern Ireland, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Turkey and Ukraine

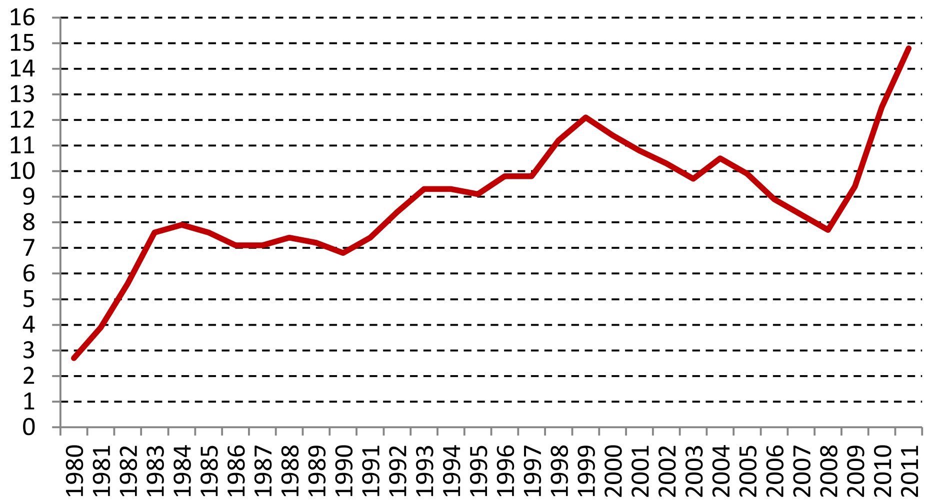
[3] The question was: „Please tell me for each of the following statements whether you think it can always be justified, never be justified, or something in between: Cheating on taxes if you have a chance." (McGee and Tyler, 2006)

From the table 3 we can see that in total the unreported taxable income accounted for 9.9 % in 2004/05. We can also see that the richest Greeks were more involved in tax evasion. Together with the progressive tax system 9.9 % of unreported income translated into the tax shortfall of 26.1 % (Matsaganis and Flevotomou (January 2010)). It is a substantial amount causing important problems from the perspective of fiscal policy.

1.3.3. Unemployment

One of the most palpable problems of Greek economy is the rising level of unemployment. In the early 1980s the unemployment was still very low, it was 2.7 % in 1980, for example, but it started to climb to much higher values quickly. During the latest crisis, the unemployment rose to even higher values, not seen in Greece before. The estimate of 2011 unemployment rate is currently 14.8 % (IMF Data Mapper, Accessed 18 April 2011). Following graph shows the unemployment from 1980 until the estimate of 2011 unemployment.

Figure 9: Unemployment in Greece from 1980 until 2011 (in %)

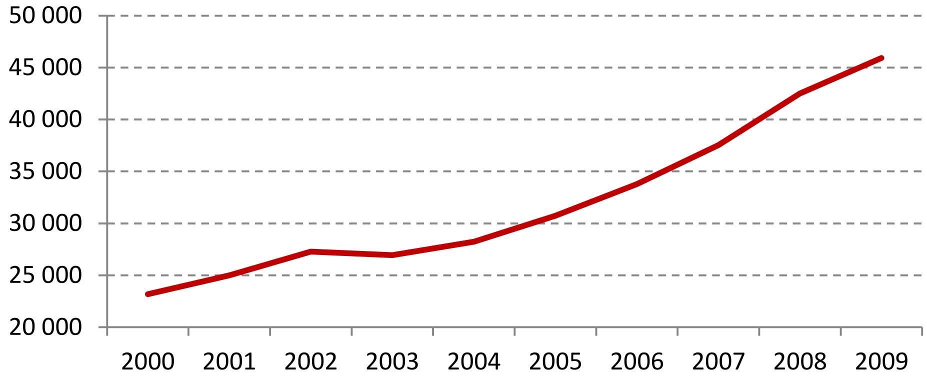


Note: 2011 value is the estimate

Source: IMF Data Mapper. Accessed 18 April 2011

The unemployment burdens government budget by two ways. It increases the social expenditures and also people not employed in the economy cannot create value which would be eventually taxable. In the following graphs we can see the evolution of Greek social spending from 2000 to 2009.

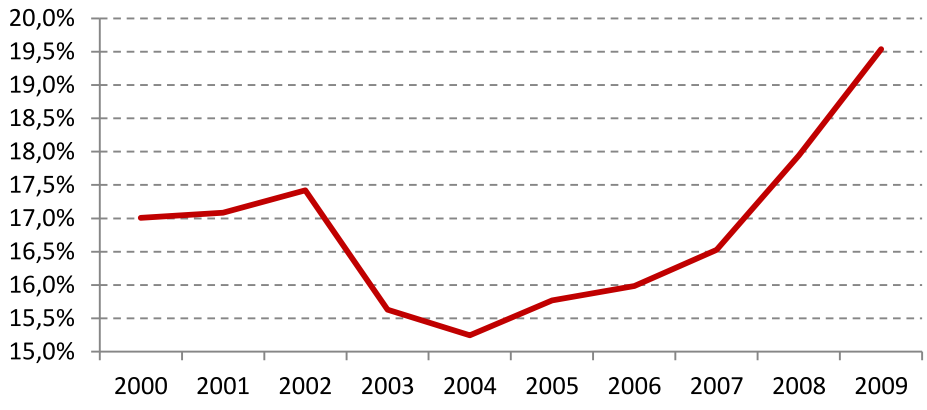
Figure 10: Greek government social spending (in EUR million)



Source: OECD Stat Extracts. Accessed 18 April 2011

We can see that the social spending continued to grow through the whole period except for year 2003. Compound annual growth rate of social expenditures is approximately 7.9 % while compound annual growth rate of the GDP is just approximately 6.2 %, both in nominal values (OECD Stat Extracts. Accessed 18 April 2011). It caused an increasing share of social expenditures on GDP in recent years, as following graph shows. We can observe that after a reduction in 2003 and 2004 there is a gradual increase until 2009. Not having newer data we do not know how the situation evolved later, even though it would be very interesting, mainly to see whether current fiscal restriction measures are effective in reducing social expenditures.

Figure 11: Share of social expenditures on GDP in Greece (in %)



Source: OECD Stat Extracts. Accessed 18 April 2011

Finally we can say that even though Greece once had very low unemployment rate, as low as below 3 %, we have seen its values multiplied during 1980s and 1990s to levels over 10 %. Latest world financial crisis pronounced weakness of Greek economy in perspective of unemployment when it almost doubled in three years: it was 7.7 % in 2008 and the latest estimates show it can be approximately 14.8 % in 2011. Unemployment is one of the biggest challenges of Greek economy affecting the government budget among others.

2. Using bond market information for evaluation of default risk of a government with regard to Greek fiscal crisis

There are many ways how the risk of default of a government can be evaluated. These methods are mostly derived from models for evaluation of default of corporations. We will briefly mention the main characteristics of all these methods before we will more deeply show the methods using bond market information only. Following the approach of Andritzky (2006) we can distinguish two types of models:

1. Structural models
2. Reduced form models

The structural models are based on the idea that there is some measure that represents the capacity of a firm/government to repay its obligations. The default is defined in this model as an event when this capacity is reached. Andritzky (2006) describe various debt capacity measures which are used in the literature on government default risk, such as GDP or foreign reserves and net exports. Generally we can say that structural models model default even as endogenous. Bond market information is not used in these models.

On the other hand, reduced form models consider default risk to be an exogenous process and do not use any debt capacity measure. Andritzky (2006) differ between two categories of reduced form models, equilibrium models and parsimonious models. Equilibrium models are based on the no-arbitrage condition. Parsimonious models are simple models which in their simplest form try to use solely the bond yield spread over the benchmark to calculate the default risk of their issuer. Reduced form models will be of our interest, because they often use bond market information to evaluate default risk of their issuer.

To develop model using information from bond market we need to develop it in several steps:

1. We need to build some probability of default concept.
2. We have to find a way how to calculate probability of default. We will also need to lay down several important assumptions in order to be able to do so.

3. We have to agree on some estimation strategy of probability of default as information of smooth zero coupon yield curve is not available on the bond market (we will see that it will be needed) and it is why we cannot calculate the probability of default directly but only using estimation. We will see that the problem reduces to the estimation of smooth zero coupon bond yield curve.

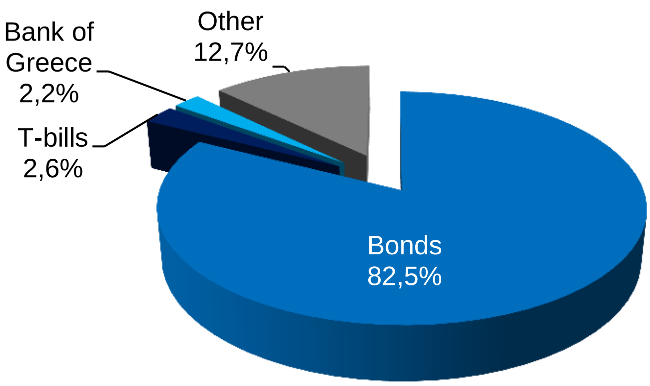
2.1. Advantages of using bond-based models in the Greek fiscal crisis

Using models based on exploiting bond market information, which is the subcategory of reduced form models, brings us many advantages over some more complex structural models. The advantages are even more evident in the extreme cases, such as the Greek fiscal crisis is.

2.1.1. Relevance

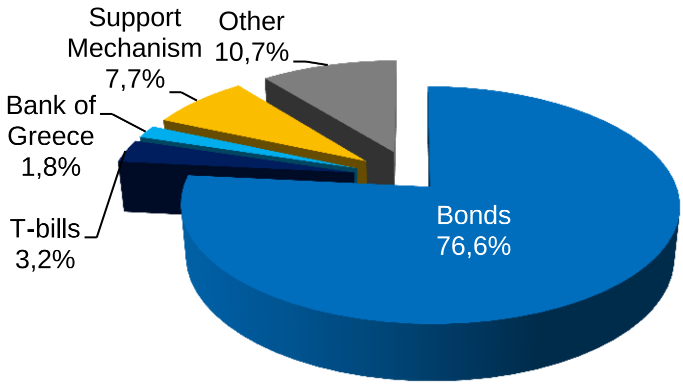
One could argue that we use just bond default risk to determine the risk of default of the whole government. But we will argue here that even though it is just an approximation, it is still reasonable to reduce our attention to the government bonds.

Figure 12: The composition of Greek government debt in September 2009



Source: Ministry of Finance of The Helenic Republic (September 2009)

Figure 13: The composition of Greek government debt in September 2010



Source: Ministry of Finance of The Helenic Republic (September 2010)

In figures 12 and 13 you can see the composition of the government debt of Greece in September 2009 and in September 2010. The choice of dates has an important reason. At first we have to mention that Public Debt Bulletins are only provided quarterly by Ministry of Finance of The Helenic Republic (March, June, September and December). The September 2009 was chosen to show the state before the crisis (in December the crisis has already become) and the September 2010 was chosen to show the effect of the international help.

We can see that even though the international help reduced the relative importance of bonds in the Greek debt portfolio a little, by 5.9 pp, the share was still dominant, 76.6 %, more than ¾ of the debt. It means that if we will approximate the probability of default of Greek government by the probability of default of their bonds, it is very good approximation as we consider the behavior of ¾ of all government liabilities.

2.1.2. Simplicity and dynamics

Even though there are many other models which have deeper and more convincing theoretical background, the simplicity, especially of the parsimonious models, is important for our purposes. Complex models use much data and often need to run heavy calculations and simulations in order to obtain a result. It is not convenient for the purposes of this thesis where we want to estimate evolution of the default probability on the daily basis and over a long period.

In structural models it is also needed to use historical data over some time sample and to estimate their future evolution. We can argue that it is not a good approach to use historical data for evaluation of default risk in the extreme cases of crises, especially in Greece. At first, used data, such as GDP, usually do not allow enough dynamics as they are not published in the desired frequency or we need to use estimates based on longer time periods, as warned by Byström and Kwon (2005), which reduces possible dynamics as well. Bond market data are high frequency data available in the frequency of up to 1 tick resolution in some cases by Reuters, for example (Reuters Wealth Manager, 2010), if needed. Secondly, in the crisis there are many points in time where important things happen, such as political decisions, which dramatically change the default probability, so the high frequency of re-calculation of the default probability is needed if we want to catch the effect of those decisions, for example. Relying on historical data could lead to out-dated estimates of default probability not corresponding to the present situation which changes quickly during the crisis. Thirdly, no simulation of future evolution is needed in the parsimonious models in order to estimate the future probability of default, because it can be fully estimated based on sovereign bond data only of different maturities.

2.1.3. Reliability of the data

Data from the bond market can be considered to be absolutely reliable in contrary to some other Greek data, especially from macroeconomic development. As we could see in the chapter 1, for example, data on GDP evolution or data on government debt had to be subject to many revisions. The situation could be better if we studied the Greek fiscal crisis from a larger time distance, when all corrections needed were done. But we can never be truly sure that this condition is met. Data on the bond market come from bond bid and ask quotations done by different traders on the market whose names are known and well documented (Reuters Wealth Manager). There is no room for need of revisions from the nature of trading itself. On the other hand there is much space for inaccuracy, both unintentional and intentional, in any accounting data. In the case of Greece this space turn up to be heavily misused as the international revisions had to be done (see chapter 1) in order to correct the data. However, any revision can be considered final for sure.

2.2. Probability of default concept

We will now introduce several definitions related to the concept of probability of default which will be crucial for further discussion. We will mainly base them on Andritzky (2006).

The most intuitive of all functions we will show here is the survival function. By the **survival function** we mean function S(t) defined as:

$$S(t) = P[\tau > t] = 1 - Q(t), \tag{2.1}$$

where τ is the time, when the default occurs, t is any chosen point in time and Q(t) is the cumulative distribution function of the default probability, which is defined below by (2.3).

Survival function can be interpreted as a function which shows what is the probability that the asset will not default prior to t, so that the asset will "survive" at least until t. It is also needed to define default intensity and cumulative probability of default as it is the counterpart of survival function. By **default intensity** q(t) we mean:

$$q(t) = P[\tau = t] = \lim_{\Delta t \to 0} (S(t) - S(t + \Delta t)). \tag{2.2}$$

It is the density of default probability at time t, in other words it is the probability that the default occurs exactly at time t. It is why Q(t), cumulative distribution function of default, can be written as a continuous sum of all default probabilities until t:

$$Q(t) = \int_{-\infty}^{t} q(s)ds. \tag{2.3}$$

Andritzky (2006) states that we usually observe time of default from time 0. Then we get several desirable properties of default intensity: t > 0, $q(t) \in \langle 0, 1 \rangle$ and $Q(\infty) = \int_0^\infty q(s)ds = 1$. It means that the default always happens in future, the default intensity must be between 0 and 1 as it is required by the probability theory and that the default always happens in unlimited time horizon.

The last important function for our purposes is the hazard function. The hazard function is slightly different from the default intensity, even though it is very similar at first sight. Hazard function $\lambda(t)$ is defined as:

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{P(t < \tau \leq t + \Delta t | \tau > t)}{\Delta t} = \frac{q(t)}{S(t)}. \tag{2.4}$$

It is a probability of default at time t given that the default did not occur before t. Mathematically there can be done a connection between (2.1), (2.2) and (2.4)[4]:

$$\frac{\partial \log(S(t))}{\partial t} = \frac{1}{S(t)}\frac{\partial S(t)}{\partial t} = -\frac{q(t)}{S(t)} \tag{2.5}$$

Then together with (2.4) we get:

$$\lambda(t) = -\frac{\partial \log(S(t))}{\partial t}. \tag{2.6}$$

2.3. Calculation of the probability of default

From the concept introduced above we cannot directly calculate what the probability of default equals, because the survival function S(t) in (2.6) is unknown. We will derive the probability of default here so that it could be calculated. The main source in the following derivation was Andritzky (2006) and Ferstl and Hayden (2010). By price of the bond we will mean a percentage of its face value.

We will have to build the derivation of the probability of default from several different concepts of yields, which we will then put together with the concept of probability of default from chapter 2.2. using a few assumptions.

A **forward rate** $F_0(t_i, T_i)$ is defined as:

$$F_0(t_i, T_i) = \frac{\int_{t_i}^{T_i} r(s)ds}{T_i - t_i}, \tag{2.7}$$

where $r(s)$ is the spot rate in time s. We can view a forward rate $F_0(t_i, T_i)$ as an implied rate at time 0 for the future time period beginning in time t_i and ending in time T_i.

Now let B(t,T) be the price of risk-free zero coupon bond at time t with maturity T and Z(t,T) be the price of risky zero coupon bond at time t with maturity T. Then continuously compounded **zero coupon bond yield to maturity** of risk-free bond is:

$$y^B(t,T) = -\frac{\log \mathrm{B(t,T)}}{T-t} \tag{2.8}$$

and continuously compounded zero coupon bond yield to maturity of risky bond is:

$$y^Z(t,T) = -\frac{\log \mathrm{Z(t,T)}}{T-t}. \tag{2.9}$$

The difference between these two yields is called **credit spread** and it is commonly used as a measure of riskiness of the bond, because credit spread is to

[4] Note: we use symbol log(x) for natural logarithm function.

compensate the risk which is bearing the risky bond in contrast to the risk-free bond. We denote credit spread s(t,T) and we can write:

$$s(t,T) = y^Z(t,T) - y^B(t,T). \quad (2.10)$$

In the case of default of the bond, there is a possibility that some value will be recovered. Let's denote $\psi \epsilon \langle 0, 1 \rangle$ a recovery rate. The recovery rate can be defined on various bases. We will define it as a fraction of market value of the bond that a bond holder will be able to get from the bond issuer when the default happens. Proportion $1 - \psi$ of the bond market value will bond holder lose forever.

Assumption 1: We will assume $\psi = 0$.

It means that we will work with the concept of outright default. Some can argue that an outright default is not a reasonable assumption in sovereign bond markets and that we should rather use an assumption of debt restructuring so that some value of the bond would be recovered (as argues Andritzky (2006) for example). Others also use dynamic approach to the recovery ratio which is then allowed to evolve in time (as in Byström and Kwon (2005), for example).

However using zero recovery rate, we do not make a bad assumption, we just measure different thing. We measure the probability of the worst case scenario which the outright default is. If the restructuring approach or dynamic restructuring approach was used, it could be misleading, especially for the dynamic approach, because we would get a probability of default in time, but each time it would be a probability of different kind of default. The static approach is crucial for us as we will want to study also its evolution in time, so we need the time series of default probabilities to be a series of fully comparable numbers. We will just need to remember that we measure probability of an outright default, not a probability of default which would happen in reality.

Assumption 2: We assume that the default risk is the only type of risk a bond bears.

The assumption of default risk being the only risk is needed for computational purposes ensuring that the model will remain parsimonious. Among other risks which we do not take into account and are also incorporated in sovereign bond valuation is interest rate risk, reinvestment risk or inflation risk, for example.

Assumption 3: We assume risk-neutral environment.

It means that all investors require the risk-free interest rate as an expected return on all investments. This assumption implies that we will obtain the risk-neutral default probabilities, not the real default probabilities. Byström and Kwon (2005) say that this probability is an upper bound of an actual probability.

We can now begin to calculate the hazard function which is our aim in this chapter. From assumption 2 and 3 we can say that the credit spread is only to compensate for default risk, because the default risk is the only risk we take into account and in addition we impose the assumption of risk-neutral environment. Then:

$$s(t,T) = -\frac{\log(1-(1-\psi)Q(T))}{T-t}. \tag{2.11}$$

From (2.10) and assumption 1, where we assume zero recovery rate of risky bond, we get:

$$s(t,T)|(\psi=0) = -\frac{\log\big(1-Q(T)\big)}{T-t} = -\frac{\log S(T)}{T-t}. \tag{2.12}$$

Let recall that $r(t)$ denotes continuously compounded spot rate at time t, then we can derive the forward rate from the following relationship between spot and forward rates:

$$e^{r(t_1)\,t_1} e^{F_0(t_1,t_2)(t_2-t_1)} = e^{r(t_2)\,t_2} \tag{2.13}$$

We can solve the equation for the forward rate in the following way:

$$\log e^{r(t_1)\,t_1} + \log e^{F_0(t_1,t_2)(t_2-t_1)} = \log e^{r(t_2)t_2} \tag{2.14}$$

$$r(t_1)\,t_1 + F_0(t_1,t_2)(t_2-t_1) = r(t_2)t_2 \tag{2.15}$$

$$F_0(t_1,t_2) = \frac{r(t_2)t_2 - r(t_1)\,t_1}{t_2-t_1} \tag{2.16}$$

We also need to define an **instantaneous forward rate**. We will use previous calculations for it:

$$f(t_1) = \lim_{t_2\to t_1} F_0(t_1,t_2) = \lim_{t_2\to t_1} \frac{r(t_2)t_2 - r(t_1)\,t_1}{t_2-t_1}, \tag{2.17}$$

which is a special case of the forward rate for some period from t_1 to t_2, but with t_1 and t_2 being limitedly close, in other words for such a very short period in future that we define instantaneous forward rate in one point in time.

Having defined the instantaneous forward rate, we can use it to obtain the instantaneous forward rate for both risk-free and risky bonds. We will use the expression (2.17) together with (2.8) and (2.9). We denote an **instantaneous forward rate of risk-free bond** as $f^B(T)$ and we can simplify it to:

$$f^B(T) = -\frac{\partial \log \mathrm{B}(T)}{\partial T} \tag{2.18}$$

In the same way we can obtain an **instantaneous forward rate of risky bond** as:

$$f^Z(T) = -\frac{\partial \log \mathrm{Z}(T)}{\partial T} \tag{2.19}$$

Now we can define, in line with the definition of credit spread, the instantaneous forward credit spread. We also impose the assumption that the default risk is the only type of risk and we use also risk-neutral environment assumption. Under those assumptions we can see that following definition of instantaneous credit spread is meaningful. We define an **instantaneous forward credit spread** as:

$$f^Z(T) - f^B(T) = -\frac{\partial \log(1-(1-\psi)Q(T))}{\partial T} \tag{2.20}$$

But we can further simplify the expression imposing assumption 1 of zero recovery rate and using (2.1) and (2.6):

$$f^Z(T) - f^B(T) = -\frac{\partial \log(1-Q(T))}{\partial T} \tag{2.21}$$

$$f^Z(T) - f^B(T) = -\frac{\partial \log S(T)}{\partial T} \tag{2.22}$$

$$f^Z(T) - f^B(T) = \lambda(T) \tag{2.23}$$

It means that the instantaneous forward credit spread is, under our assumptions, the hazard rate. So the hazard rate of an outright default at some time T is the difference between instantaneous forward rates of risky bond and risk-free bond. It means that the problem of estimation of default probability is very close to the problem of estimation of smooth zero coupon yield curves for both risky and riskless bonds. We have to stress once again that the estimate of instantaneous risk of default needs the zero coupon yield curve to be smooth, thus differentiable with respect to T to be able to calculate the hazard function in parametric form which is a very desirable outcome.

2.4. Estimation of the smooth zero coupon bond yield curve

As we do not know the smooth zero coupon bond yield curve, but we only know data on coupon bonds, we will have to derive the zero coupon bond yield curve from coupon bonds data using some estimation procedure. Ferstl and Hayden (2010) show several methods known as Nelson/Siegel and Svensson method and cubic spline interpolation method. Those methods are typical parametric and non-parametric methods respectively. They also show the implementation of both methods using computation software R. We will have to use a parametric model to obtain a curve differentiable with respect to time to use it for estimation of hazard rate.

2.4.1. Introduction to the zero coupon bond yield curve estimation

It is useful to define some new terms related to the estimation of zero coupon bond yield curve. Many definitions from previous sections are applicable for estimation as well, but we will want to work with definitions re-defined so that they will use matrix notation. It is important, because we need to compute with more bonds at once in the estimation process and it is more convenient to use matrix notation rather than to compute with the system of many equations. The definitions are based on Ferstl and Hayden (2010), but the notation had to be changed significantly to be compatible with the notation used before.

At first we will define several basic bond features in a matrix notation. We define a **matrix of maturities** as:

$$M = \{m_{i,j}\}, i = 1, \dots t, j = 1, \dots k \tag{2.24}$$

We define a **matrix of cash flows** as:

$$C = \{c_{i,j}\}, i = 1, \dots t, j = 1, \dots k \tag{2.25}$$

The number of rows t is the number of cash flows of the bonds in the set of all bonds with the highest number of cash flows and k is the number of bonds in the set of all bonds. Each bond has two pieces of information coded in these two matrices: matrix C stores information on all individual cash flows that will be realized to the bondholder and matrix M attaches to each cash flow its time of occurrence. If the number of cash flows for some bonds is less than for the bond with the most cash flows, remaining cells of the matrix are filled with 0. We also count nominal value paid at maturity as one of the cash flows.

Similarly we define a **price vector** as:

$$p = p^c + a = \left\{p_j = p^c{}_j + a_j\right\}, j = 1, \dots k \tag{2.26}$$

p^c is the row vector of clean prices of bonds j = 1,…k. In other words, those are the quoted prices at the market. a is the row vector of accrued interests related to bonds j = 1,…k. By the **vector of accrued interests** we mean:

$$a = \left\{ a_j = \frac{n_j^1}{n_j^2} c_{i,j} \right\}, i = 1, \dots t, j = 1, \dots k \tag{2.27}$$

n_j^1 is the number of days since last coupon payment for j-th bond, n_j^2 is the number of days in current coupon period for bond j.

To show the relationship between the bond prices and its cash flows we have to define a **discount factor matrix** as:

$$D = \left\{ \delta\left(m_{i,j}\right) = e^{-r(m_{i,j})m_{i,j}} \right\}, i = 1 \dots t, j = 1, \dots k, \tag{2.28}$$

where $r(m_{i,j})$ denotes the continuously compounded spot rate at time of occurrence of an i-th cash flow of j-th bond.

We can use the definitions of a price vector and discount factor matrix to obtain an expression showing the relationship between the price vector and discount factor:

$$p_j = p^c{}_j + a_j = \sum_{i=1}^{t} c_{i,j}\, \delta\left(m_{i,j}\right), j = 1, \dots k \tag{2.29}$$

In the matrix notation the equation can be rewritten as:

$$p = \iota^T (C \cdot D), \tag{2.30}$$

where ι denotes a column vector of ones and $\cdot$ denotes element-wise multiplication of matrices, not a matrix multiplication. We can also use the relations (2.28) and (2.29) to show how we can compute the yield till maturity of coupon bonds. We denote the yield till maturity of bond j as y_j. Then the yield till maturity is the solution for y_j in the following equation:

$$p^c{}_j + a_j = \sum_{i=1}^{t} c_{i,j}\, e^{-y_j m_{i,j}}, j = 1, \dots k \tag{2.31}$$

For the estimation procedure it will be useful to define a Macaulay duration vector. We will define it in this way:

$$d = \frac{\iota^T (C \cdot M \cdot D^{YTM})}{\iota^T (C \cdot D^{YTM})}, \tag{2.32}$$

where the division is element-wise and D^{YTM} is the matrix of discount factors using the yield till maturity as follows:

$$D^{YTM} = \{e^{-y_j m_{i,j}}\}, i = 1 \dots t, j = 1, \dots k \tag{2.33}$$

2.4.2. Nelson-Siegel method

Nelson-Siegel method is one of possible methods for so called indirect estimation of zero coupon bond yield curve. It means that we try to find some curve which can be described in a parametric way and which satisfies theoretical conditions as well as possible. Nelson and Siegel (1987) introduced a parsimonious model for modeling yield curves. Ferstl and Hayden (2010) present its implementation for use in computation program R.

The functional form of the instantaneous forward rate according to Nelson and Siegel (1987) used by Ferstl and Hayden (2010) is:

$$f(m_{i,j}, \beta) = \beta_0 + \beta_1 \exp\left(-\frac{m_{i,j}}{\tau}\right) + \beta_2 \left[\left(\frac{m_{i,j}}{\tau}\right) \exp\left(-\frac{m_{i,j}}{\tau}\right)\right], \tag{2.34}$$

where β is the vector of parameters $\beta = (\beta_0, \beta_1, \beta_2, \tau)$. When we apply the relation that the spot rate is the average of forward rates, which is:

$$r(m_{i,j}, \beta) = \frac{1}{m_{i,j}} \int_0^{m_{i,j}} f(m_{i,j}, \beta) d\, m_{i,j}, \tag{2.35}$$

we get the relation for the spot curve:

$$r(m_{i,j}, \beta) = \beta_0 + \beta_1 \frac{1 - \exp\left(-\frac{m_{i,j}}{\tau}\right)}{\frac{m_{i,j}}{\tau}} + \beta_2 \left[\frac{1 - \exp\left(-\frac{m_{i,j}}{\tau}\right)}{\frac{m_{i,j}}{\tau}} - \exp\left(-\frac{m_{i,j}}{\tau}\right)\right] \tag{2.36}$$

Now we have to estimate the unknown parameter vector β. Ferstl and Hayden (2010) use weighted least squares and globally optimal parameter estimation method. The method is based on minimizing the error between the observed bond prices and theoretical bond prices. At first, they mention the importance of weighting of price errors to reduce the problem of heteroskedasticity. For a bond j they use a weigh ω_j in the following form:

$$\omega_j = \frac{d_j^{-1}}{\sum_{i=1}^{k} d_i^{-1}}, \tag{2.37}$$

Then they show the objective function which is used in the optimization procedure. It is function $F(\beta)$, which has the following form:

$$F(\beta) = (p - \iota^T (C \cdot D^{YTM}))^2 \omega^T \tag{2.38}$$

Objective function calculates in fact the weighted errors of estimated bond prices for given vector of parameters β. The optimization procedure is based on the idea of minimizing the objective function subject to restrictions which are derived in Ferstl and Hayden (2010) in the Appendix A. It means that we get the parameters for which the pricing of bonds is as precise as possible given the model.

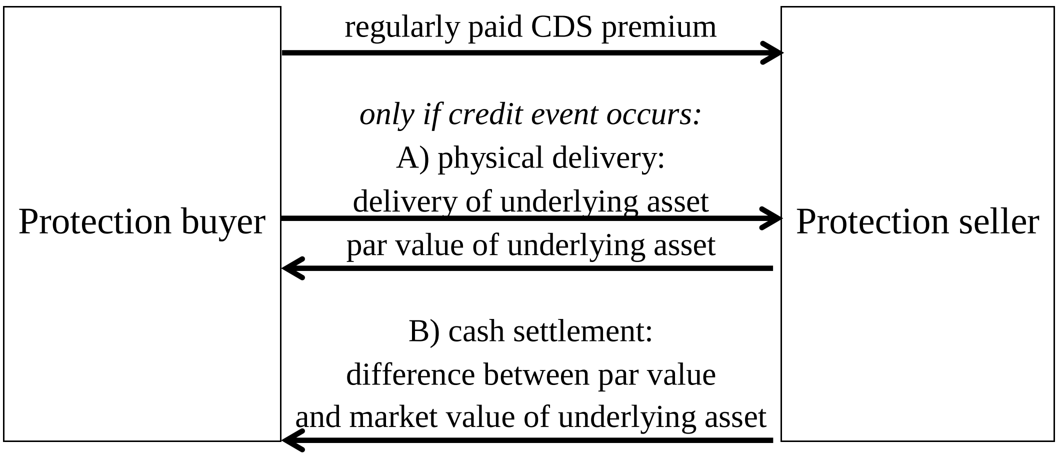
3. Using credit default swaps for evaluation of government credit risk

As we mentioned before, using bond market information for estimation of credit risk is by far not the only option to try to estimate the credit risk of the government. In this chapter the possible use of CDS for this purpose will be discussed as an alternative. The main source will be Andritzky (2006).

3.1. CDS as an instrument

The CDS is a credit derivative instrument developed to provide one party, which is called credit protection buyer, insurance against some kinds of credit events associated with the underlying asset. CDS is an OTC instrument, so it is negotiated directly between counterparties. CDS transfers the credit risk on the other party, which is called protection seller. The protection buyer, however, does not have to hold the underlying asset to buy a CDS from protection seller. In the following figure we can see the cash flow associated with the CDS.

Figure 14: CDS cash flow



Source: Author’s figure

CDS cash flow follows an easy pattern. While no credit event occurs, there are only regular payments from protection buyer to protection seller called CDS premium. The CDS premium is usually paid quarterly (Andritzky, 2006). While a credit event occurs, there are basically two different kinds of possible settlements. The physical delivery means that the protection buyer delivers protection seller the underlying asset and protection seller pays protection buyer the par value of the asset. There can be defined so-called deliverable bonds, which are bonds accepted in case of physical delivery. Then protection buyer delivers CTD (cheapest to deliver) deliverable bond. In the case of cash delivery the protection seller pays the protection buyer the difference between the par value and market value of the asset. The CDS is negotiated for a predefined period of time. CDS is terminated if this time passes or if credit event occurs.

Andritzky (2006) mention five possible credit events: „(i) a change in coupon rates, (ii) a change in principal amount, (iii) a postponement of interest or principal payment date, (iv) a change in ranking of priority, and (v) a change in payment of interest or principal to a non-permitted currency.“

We will use government bonds as an underlying asset in the case of estimation of probability of default of government. Then, if the credit event occurs, the protection buyer tries to deliver the protection seller the cheapest-to-deliver bond, because the physical delivery is most common in practice (Andritzky, 2006). Within 30 business days usually follows the payment of par value by the protection seller (Andritzky, 2006).

3.2. Fair value of the CDS premium

A fair value of the CDS premium is determined from equality of two so-called "legs". One leg is called premium leg and expresses the present value of the CDS premium. The other leg is called protection leg and it is the present value of the credit event. The CDS premium has a fair value if the two legs are equal, so if the protection buyer pays the value of premium leg and receives a value of protection leg through the CDS contract. We can express this logic more formally. We have to mention that we assume risk-neutral probability measure. The present value of premium leg can be expressed as:

$$g(t,c) = \frac{c}{4}\sum_{i=1}^{N} \exp\left(-\int_0^{t_i} r_u + \lambda_u du\right), \tag{3.1}$$

where c is the CDS premium (expressed in annual terms), N is the total number of premium payments which are assumed to be paid quarterly, t_i is the time when the i-th premium payment is done, r_t denotes the continuous risk-free interest rate at time t and λ_t is the hazard rate of credit event at time t. It means that the value of premium leg equals to the sum of values of all future premium payments. Each payment has the value equal to the nominal value of it discounted continuously by the risk-free interest rate and hazard rate. The discounting by hazard rate is essential as if the credit event triggered at time t, the contract would be terminated and no further payments by the protection buyer would be done. So there is discounting by the hazard rate of credit event to involve this risk in the valuation of premium leg.

The rationale behind the present value of protection leg is similar, but it is more complicated. The first think we have to bear in mind is that the protection leg's value is generated by credit event. If there was no probability of credit event, protection leg would have no value. We will scale par value of the underlying bond to 1. We denote by τ the time of default of the bond and by $\tau_d = \tau + d$ the settlement day, when protection seller pays protection buyer the difference between par value of the bond and fractional recovery of the face value which is saved after default at time τ_d (denoted by $\omega(\tau_d)$) and accrued interest $A(\tau_d)$ which protection buyer has to pay also. In addition protection seller receives a fraction of CDS premium which is accrued at time of default c^*. The value of the protection leg at time of default is then:

$$1 - \underbrace{\omega(\tau_d)\exp\left(-\int_{\tau}^{\tau_d} r_u du\right)}_{\widehat{\omega}(\tau_d)} - \underbrace{A(\tau_d)\exp\left(-\int_{\tau}^{\tau_d} r_u du\right)}_{\hat{A}(\tau_d)} - \frac{c^*}{4} \qquad (3.2)$$

The recovery value and accrued interest are both discounted at risk-free rate during the period between the default and actual settlement between CDS counterparties.

It is however also needed to compute the present value of the protection leg at time 0. It can be expressed as:

$$h(t,c,d) = \int_0^{t_N}\left(1 - \widehat{\omega}(\tau_d) - \hat{A}(\tau_d) - \frac{c^*}{4}\right)\lambda_u \exp\left(-\int_0^u r_v + \lambda_v dv\right) du \qquad (3.3)$$

It means that for every time moment between the time 0 and t_N, which is the time when the last premium payment occurs and CDS is terminated, the value of possible credit event at that time is multiplied by hazard rate of the credit event λ_u to take into account the probability the payment will actually be done and it is also discounted by the risk-free rate and hazard rate of previous credit events, because it is possible that the credit event has already happened by that time and CDS has already terminated.

The current fair CDS premium, denoted by c_t^f is then determined by the equality of premium leg and protection leg. If CDS premium on market is fair, then c_t^f can be considered the CDS spread which is quoted. The final equation to determine the fair value is then:

$$g\left(t, c_t^f\right) = h\left(t, c_t^f, d\right) \tag{3.4}$$

3.3. The recovery estimation

The main measure of credit risk in the method proposed by Andritzky (2006) is the recovery ratio. There are two different concepts of recovery ratios needed to be introduced. The first is so-called RMV, the recovery of market value, and the second one is RFV, recovery of face value. Using RMV concept, we mean by recovery ratio the pre-default fraction of the market value of the bond that is preserved even after default. If we use RFV concept, we mean by recovery ratio the fraction of value of the bond that is preserved after default expressed as a percentage of its face value.

It is also important to introduce the CDS basis before the estimation of recovery. The CDS basis is the difference between the CDS spread and bond spread, both CDS and bond having the same maturity. It is the feature that makes the estimation of recovery more complicated. CDS basis is positive when CDS premium is higher than corresponding bond spread. There are various incentives for CDS basis to raise or lower on different occasions. Anything making a CDS contract better for protection buyer makes the basis to rise and what makes it worse for protection buyer lowers the basis. For example simply the fact that the protection buyer can deliver a bond for its market value while is insured at par value rises the basis. On the other hand, the counterparty risk, for example, risk of default of the protection seller, can lower the basis. There is, however, by far the most important driver, which is the differing concept of recovery in CDS and bond point of view. For CDS we use RFV concept (recovery fraction denoted by ω) and for bonds we use RMV concept (recovery fraction denoted by ψ). It causes that CDS spread cannot be, except for special circumstances, equal to the bond's spread with corresponding maturity. Andritzky (2006) shows that this difference between recovery concepts is so important that it is not convenient “to assess the relative value of the position” by the CDS basis and it is better to estimate recovery rate and hazard rate.

We will now discuss the simplest method Andritzky (2006) shows. It is possible to use a model based on no arbitrage in pricing of two instruments: CDS and bond with the same or at least very similar maturity as is the length of CDS contract. We can begin with the equation for dirty price of a bond:

$$w_{RFV}(\lambda_t, \omega_t) = \sum_{i=1}^{I} C_i \exp\left(-\int_{t_0}^{t_i} r_u + \lambda_u \, du\right) + \omega \sum_{i=1}^{I} \exp\left(-\int_{t_0}^{t_i} r_u \, du\right)\left(\exp\left(-\int_{t_0}^{t_{i-1}} \lambda_u \, du\right) - \exp\left(-\int_{t_0}^{t_i} \lambda_u \, du\right)\right) \tag{3.5}$$

The bond pays I coupon payments C_i at times t_i for i = 1, …I. ω is the recovery value using RFV concept. r_t is the risk-free rate at time t and λ_t is the hazard rate at t. The coupon payments are done in discrete time intervals, while the risk of a credit event is assumed to be possible any time. Please, note that the equation already considers an accrued interest. It can be further expanded by adding following term to the equation:

$$\sum_{i=1+g}^{I} N_i \exp\left(-\int_{t_0}^{t_i} r_u + \lambda_u \, du\right), \tag{3.6}$$

where N_i are possible so-called amortization payments, payments done usually together with coupon payments after some so-called grace period g, which repay some part of the par value in advance, feature sometimes occurring for sovereign bonds.

The second valuation equation is the equation for CDS spread which can be derived from equation (3.4) as a function of hazard rate and recovery of face value:

$$c_t = f(\lambda_t, \omega_t) \tag{3.6}$$

Then we can combine this equation with the equation for market price of bond with corresponding maturity, where we assume that current market price is equal to its fair value from equation (3.5):

$$P_t = w_{RFV}(\lambda_t, \omega_t) \tag{3.7}$$

If we, in addition, assume constant hazard function and recovery rate function for all maturities (but with constant value varying each day), we can solve those two equations for λ_t and ω_t, which was our goal.

Andritzky (2006) also shows a three-instrument model, where using additional information on CTD bond price it is possible to calculate also the recovery using RMV concept, not only RFV as above. It is also possible to complicate the model using non-constant hazard and recovery rate function. On the other hand we can simplify the model considerably by imposing zero recovery rate if we do not mind the loss of realism in this way.

An interesting extension could be done by allowing the counterparty risk in this model, so allowing protection seller to default. A counterparty risk surely plays some role which can be negligible if the CDS protection seller is very trustworthy, but should not be disregarded as it can bias the estimate produced by the model, because counterparty risk lowers the CDS basis. We have to say that it also depends on the fact if the counterparty risk is properly perceived by the protection buyer and so if it is included properly in the CDS premium and basis respectively.

4. Case study of Greek government default risk

In chapter 2 it was shown how the method of Nelson and Siegel (1987) is applicable for estimation of default of a government using government bond market information.

4.1. Research aims

This study will try to estimate the probability of default of Greek government. The main reason is to estimate its development during the crisis. We will study the period from 17 March 2009 until 9 March 2011. There were no exact dates which would be reasonable to select, so a period of almost 2 years was selected to cover the period before the Greek debt crisis began also. As the crisis did not come to the end by the completion of this thesis, the end of the crisis could not have been covered, unfortunately.

Using the estimated evolution of probability of default, several hypotheses will be tested using the time series analysis to show whether some important events affected the probability of default of the Greek government.

At last, but not least, it will be also shown what are main advantages and disadvantages of use of the bond-based parsimonious method based on Nelson and Siegel (1987) described in chapter 2 for purposes of estimation of the probability of default.

4.2. Research hypotheses

There will be studied following hypotheses in this empirical study:

1. 11.11.2009 was the trigger point of the crisis.
2. The probability of default of Greek government during the Greek fiscal crisis of 2010 rose significantly.
3. The probability of default of Greek government fell significantly after the announcement of the aid package for Greek government.
4. The probability of default rose gradually even before the crisis.

4.3. Methodology

We will use the bond-based parsimonious method based on Nelson and Siegel (1987) as described in chapter 2. At first we have to choose a benchmark, zero-risk government bonds, to be able to estimate the probability of default of another government. We have to find such a government bonds which are issued in the same currency as Greek government bonds and at the same time the benchmark government has to be considered as very credible. The best choice in the Eurozone seems to be the German government bonds.

Then the zero-coupon yield curve estimation procedure will be done for both German and Greek government bonds. The advantage of the chosen parametric method is that we can use the parameters (vector β) from the estimated zero-coupon yield curve to directly calculate the instantaneous forward curve for both countries. According to the method shown in chapter 2 we can then directly calculate the hazard function for each day of the selected period as an instantaneous forward credit spread curve, which is the difference between the instantaneous forward rate curve for Greece and Germany.

When we gain the estimate of the hazard function of Greece evolving in time, we have to decide on the time horizon which we will like to study as we will, in fact, be able to estimate the probability of default in any time in future using the estimated hazard function. There are, however, some reasonable bounds of time horizon we can use. It must be at least 0, it means the probability that the Greek government will default at observation day and at most the time horizon of the optimization process, which must be set. It was set to 20 year horizon for this study as it was seen as a reasonable upper bound, also because just a few observed bonds had longer maturity.

For the purposes of the time series analysis we will have to select one certain horizon of hazard function to obtain a hazard rate for certain horizon developing in time. To set the horizon to 0 can be interesting, because then we measure the current default probability as seen by the bond market. However we will see that measuring the hazard function at 0 can lead to extreme volatility and extreme values, because the shape of hazard function changes very much for low horizons with different data. We will discuss later the optimal horizon.

For testing of hypothesis 1 we will use a Chow test for structural break. We will run three OLS regression models: one will estimate trend of probability of default during the whole tested period, the second will estimate trend during the period before 11. 11. 2009 and the third will estimate it after 11. 11. 2009. The Chow test should then show if the difference between the two periods is so large that it is better to use two models for them, in other words, if there is a significant structural break. The Appendix 4 shows the econometrics of the Chow test. As a source for this appendix serves Baltagi (2008).

The rise or decline in the probability of default in hypotheses 2, 3 and 4 will be tested using OLS estimation procedure for detection of a trend during selected suitable time period. The slope parameter of the trend will be then tested for positive or negative value.

4.4. The dataset

The data on German and Greek government bonds were obtained using the Reuters Wealth Manager online application. All coupon bonds which existed through the entire selected time period and accessible through the student account of Reuters Wealth Manager were used. Both governments also issue several bonds in foreign, non-Euro currencies, which were also omitted. Following table summarizes all bonds involved in the study. By the ISIN we can distinguish the German and Greek bonds by the code “DE” or “GR”. 34 German and 20 Greek government bonds were used in total.

Table 4: Bonds used for estimation

ISIN	Coupon rate	Issue date	Maturity date
DE0001134468	0.06	20.6.1986	20.6.2016
DE0001134492	0.05625	31.8.1986	20.9.2016
DE0001134922	0.0625	4.1.1994	4.1.2024
DE0001135044	0.065	4.7.1997	4.7.2027
DE0001135069	0.05625	23.1.1998	4.1.2028
DE0001135085	0.0475	9.10.1998	4.7.2028
DE0001135143	0.0625	21.1.2000	4.1.2030
DE0001135176	0.055	27.10.2000	4.1.2031
DE0001135184	0.05	25.5.2001	4.7.2011
DE0001135192	0.05	4.1.2002	4.1.2012
DE0001135200	0.05	5.7.2002	4.7.2012
DE0001135218	0.045	10.1.2003	4.1.2013
DE0001135226	0.0475	31.1.2003	4.7.2034
DE0001135234	0.0375	4.7.2003	4.7.2013
DE0001135242	0.0425	31.10.2003	4.1.2014
DE0001135259	0.0425	28.5.2004	4.7.2014
DE0001135267	0.0375	26.11.2004	4.1.2015
DE0001135275	0.04	28.1.2005	4.1.2037
DE0001135283	0.0325	20.5.2005	4.7.2015

DE0001135291	0.035	25.11.2005	4.1.2016
DE0001135309	0.04	19.5.2006	4.7.2016
DE0001135317	0.0375	17.11.2006	4.1.2017
DE0001135325	0.0425	26.1.2007	4.7.2039
DE0001135333	0.0425	25.5.2007	4.7.2017
DE0001135341	0.04	16.11.2007	4.1.2018
DE0001135358	0.0425	30.5.2008	4.7.2018
DE0001135366	0.0475	25.7.2008	4.7.2040
DE0001135374	0.0375	14.11.2008	4.1.2019
DE0001141489	0.035	24.3.2006	8.4.2011
DE0001141497	0.035	29.9.2006	14.10.2011
DE0001141505	0.04	30.3.2007	13.4.2012
DE0001141513	0.0425	28.9.2007	12.10.2012
DE0001141521	0.035	28.3.2008	12.4.2013
DE0001141539	0.04	26.9.2008	11.10.2013
GR0110019214	0.038	1.2.2008	20.3.2011
GR0114019442	0.039	24.5.2006	20.8.2011
GR0114020457	0.041	2.3.2007	20.8.2012
GR0114021463	0.04	26.3.2008	20.8.2013
GR0114022479	0.055	28.1.2009	20.8.2014
GR0124015497	0.0535	30.1.2001	18.5.2011
GR0124018525	0.0525	17.1.2002	18.5.2012
GR0124021552	0.046	17.1.2003	20.5.2013
GR0124024580	0.045	13.1.2004	20.5.2014
GR0124026601	0.037	22.2.2005	20.7.2015
GR0124028623	0.036	18.1.2006	20.7.2016
GR0124029639	0.043	17.1.2007	20.7.2017
GR0124030645	0.046	13.5.2008	20.7.2018
GR0124031650	0.06	11.3.2009	19.7.2019
GR0128001584	0.075	20.5.1998	20.5.2013
GR0128002590	0.065	11.1.1999	11.1.2014
GR0133001140	0.065	22.10.1999	22.10.2019
GR0133002155	0.059	24.4.2002	22.10.2022
GR0133003161	0.047	30.5.2007	20.3.2024
GR0138001673	0.045	7.3.2005	20.9.2037

Source: Reuters Wealth Manager

Data on daily closing prices of these bonds were obtained and their basic specification, like ISIN number, coupon rate, issue date and maturity date were obtained from the online Reuters database, but several other features had to be calculated, because they were not directly available from the database and they were needed by the R package termstrc by Hayden and Ferstl (2010). Data which were to be calculated were accrued interest of each bond for each day of the studied time period and also all future cash flows from all bonds from the perspective of all days in the studied time period. The calculation of all these values was programmed in VBA, using which also much other necessary preparation of data was done in order to make them usable in R package termstrc.

As far as the time period is concerned, Germany and Greece do have different trading days, so only the shared trading days were considered, as the method needs always both studied and benchmark bonds to be traded on the day for which we want to run the estimation procedure. There were 474 shared trading days from 17 March 2009 until 9 March 2011.

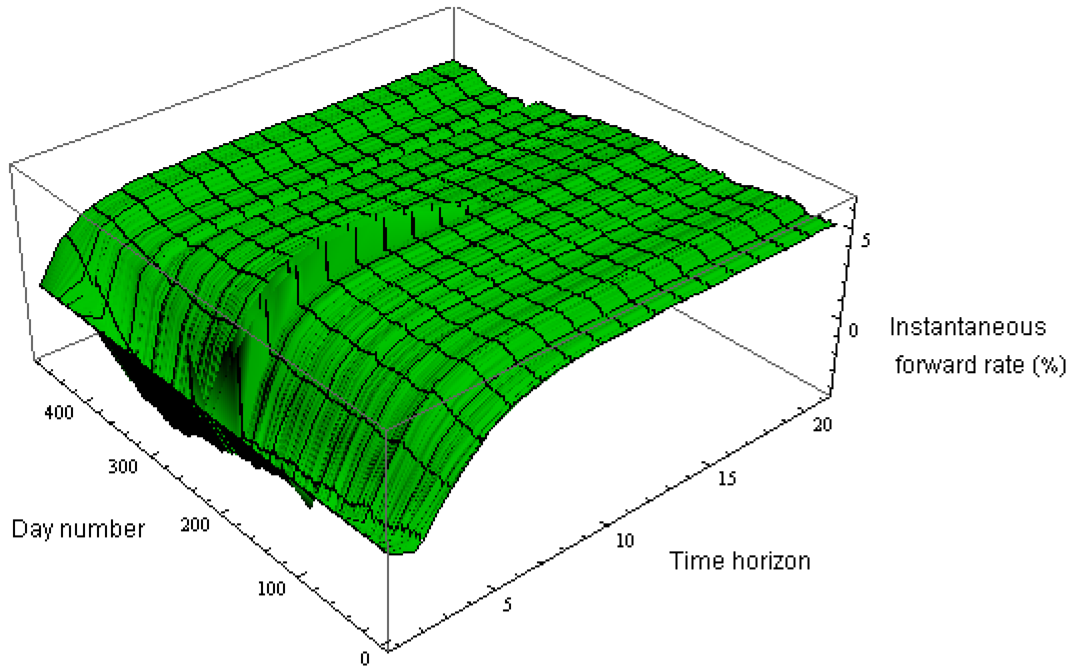
4.5. The estimates

At first, the estimates of vector of parameters beta were run. The range of maturities was set from 0 to 20. The estimation package termstrc also allows us to impose constraints for a parameter tau. There were set no constraints. We have to mention that the use of constraints for tau is recommended by Ferstl and Hayden for performance reasons together with the reasons of smoother evolution of parameters, because solutions out of bounds even with better values of objective function are not taken into account, which can lead to more similar results, but with the loss of precision. Graphs in Appendix 5 show the evolution of parameters for Germany and Greece using estimation procedure with stated settings.

4.5.1. Instantaneous forward curves

Using estimated parameters we can compute the estimated instantaneous forward curves. Following graph shows the resulting instantaneous forward curves for the entire period from 17 March 2009 until 9 March 2011 for Germany.

Figure 15: Estimated instantaneous forward curve of Germany evolving in time (17 March 2009 until 9 March 2011)



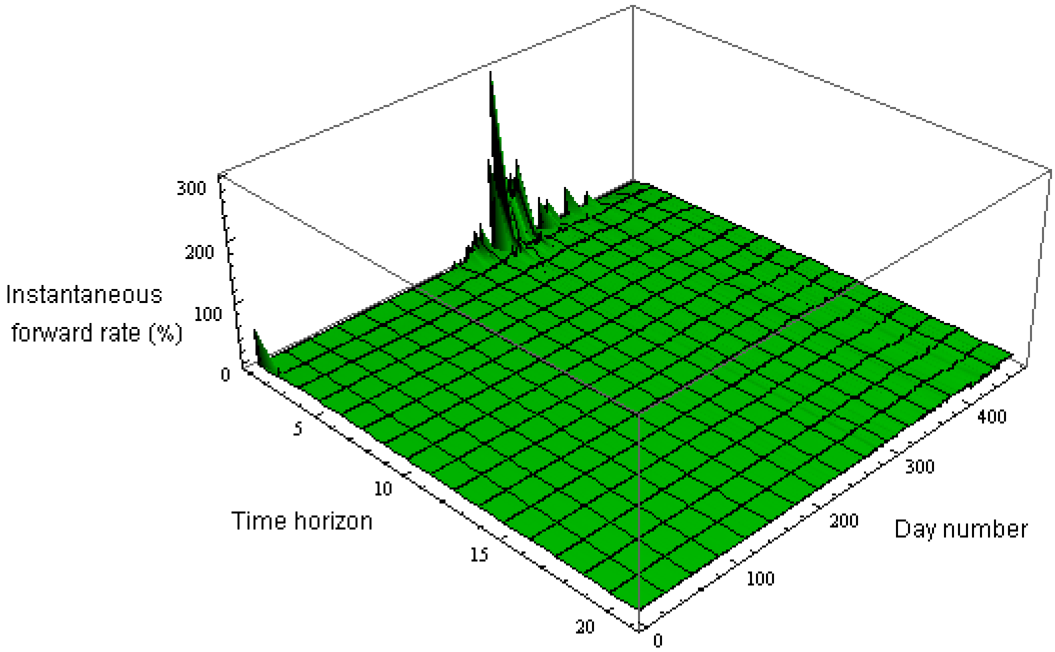
Source: Author's computations

The axis "Day number" tells us on what day we are observing the instantaneous forward rate curve. It ranges from 17 March 2009 until 9 March 2011. On the axis "Time horizon" we can see for what time horizon the instantaneous forward rate is valid. The axis "Instantaneous forward rate" shows the estimated value of the forward rate for a given day and time horizon in %.

We can see in fact two notable features of this graph. At first, some values go below zero for very small time horizons. The second feature are two very different curves not smoothly fitting into other curves. Those two features are caused by the optimization procedure and by the properties of Nelson and Siegel curve. They cannot be avoided for our dataset with the used method. The negative instantaneous forward rates are, however, especially for short time horizons, not so unrealistic in case of Germany, which is usually used as a benchmark country with lowest interest rates in the EU.

The situation is however much more unusual for the estimated instantaneous forward curves of Greece which exhibited the fiscal crisis. Following graph shows them for the whole period.

Figure 16: Estimated instantaneous forward curve of Greece evolving in time (17 March 2009 until 9 March 2011)



Source: Author's computations

The graph is now turned by approximately 90° clockwise to be able to better observe the estimated curves. We can clearly see that the behavior of instantaneous forward rate for low time horizons is very unrealistic as it reaches almost 300 % in peak during the crisis. To show if the curves are actually fitting our data well while they have relatively extreme shapes, mainly for Greece, we can compute RMSE for both Greece and Germany. Following table shows the results of this goodness of fit measure. RMSE is shown both for bond prices and for yields until maturity. Please note that the results are in absolute values and that the prices of the bonds were scaled to the nominal value of 100.

Table 5: RMSE of the model for prices and yields

	Greece	**Germany**
price	1.500243	1.93726
yield	1.558057	1.14683

Source: Author's computations

For the case of Greece, several other estimates were run using restrictions on tau parameter proposed by Ferstl and Hayden (2010) to achieve smoother evolution of parameters and also to achieve more realistic values of instantaneous forward curves at zero. Any restrictions, however, lead to the increase in RMSE and the unrealistically high levels of instantaneous forward rates at 0 were not lowered. Because of this we will use the original results further claiming that they are the best results we can obtain using our method on our dataset.

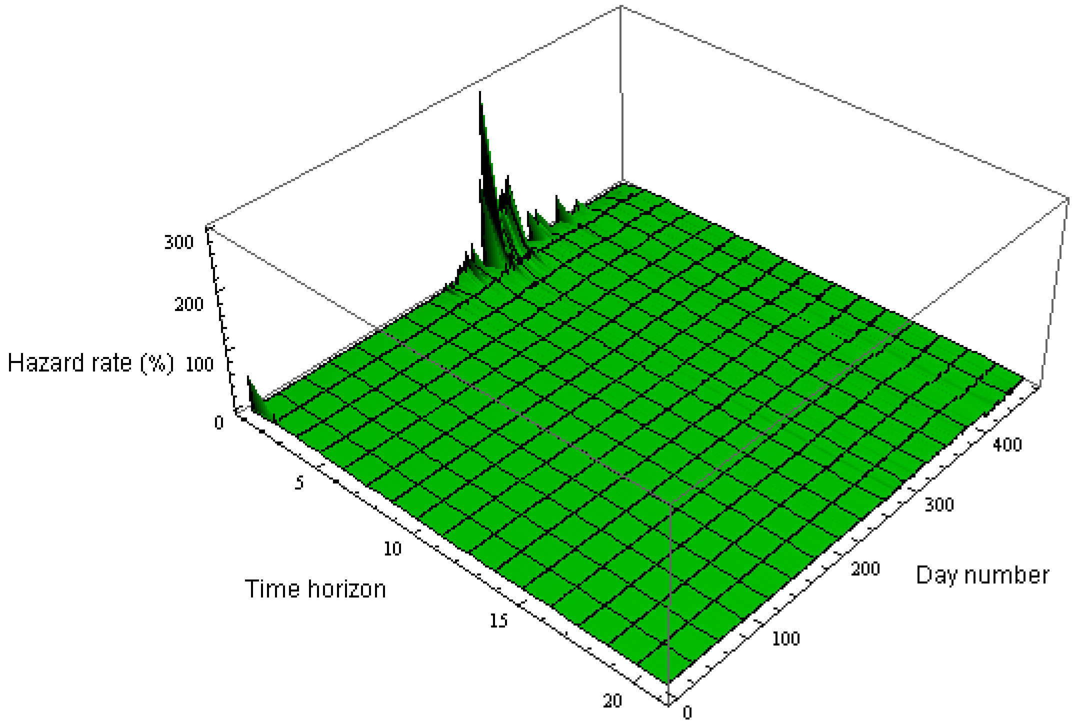
The high values of instantaneous forward rates at 0 are caused by the lack of observations of bonds with zero or very short time to maturity. Even though there are observations with relatively short time to maturity, it is still not sufficient. The curve which we try to fit using our data can fit well the bonds in the dataset, but when we cannot observe bonds with no or very few days to maturity, it causes the curve to have very volatile slope for those non-observed time horizons, because it does not try to fit any values there. We will, however, try to solve this issue as well as possible.

4.5.2. Hazard function

Using the estimated instantaneous forward curves we can derive the hazard function evolving in time for Greece. As we know from the methodological part, we can get the hazard function as a difference between Greek and German instantaneous forward curves assuming no recovery. Please note that if we used changing recovery rate, we would get a series of hazard functions which would not be comparable over time, which we need for time series analysis. If we included a recovery rate, we would increase the estimate of probability of default, so we can say the hazard rate computed using no recovery is a lower bound of hazard rates supposing any rate of recovery. So we can interpret it as an estimate of hazard rate of Greece supposing no recovery even though in reality some recovery is highly probable. However it is also interesting for our purposes, because we are mainly interested in the evolution of the probability of default rather than in the actual probability of default supposing some changing recovery value.

Below we can see the estimated evolution of the hazard function. To familiarize with the meaning of the picture, it is the best approach to imagine that we can choose a day from 17 March 2009 and 9 March 2011 and observe it. The chosen day is one of the days from the axis "Day number". The day number is the ordinal number of the day in whole set of observed days (we observe only days when both Greek and German bond markets were open). Then the axis "Hazard rate" shows the hazard rate in some time horizon on axis "Time horizon" in years from the point of view of the chosen day. The hazard rate is here the **probability of default** of Greek government at time given by the time horizon given that the government had not defaulted yet.

Figure 17: Estimated hazard function of Greece supposing no recovery (17 March 2009 until 9 March 2011)



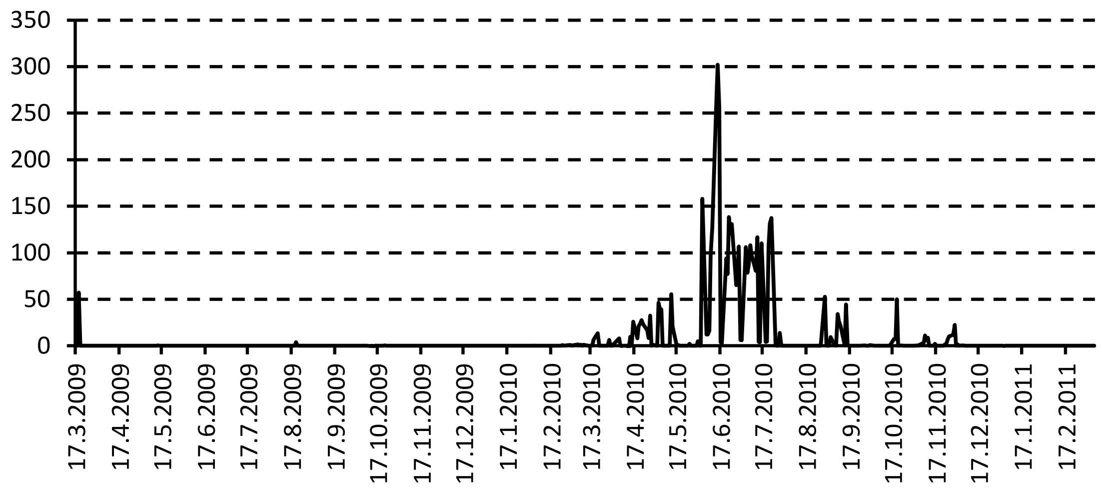
Source: Author's computations

We can see that the hazard rate for short time horizons was very high during the worst periods of the crisis. It was more than 100 % which is not possible as 100 % means certainty and there can be no higher value of probability than certainty. This outcome is however expectable from the instantaneous forward rate curve estimates from previous section. It however can still make sense to use these estimates as a measure of risk if we approach them carefully as proposed below.

4.5.3. Testing of hypotheses

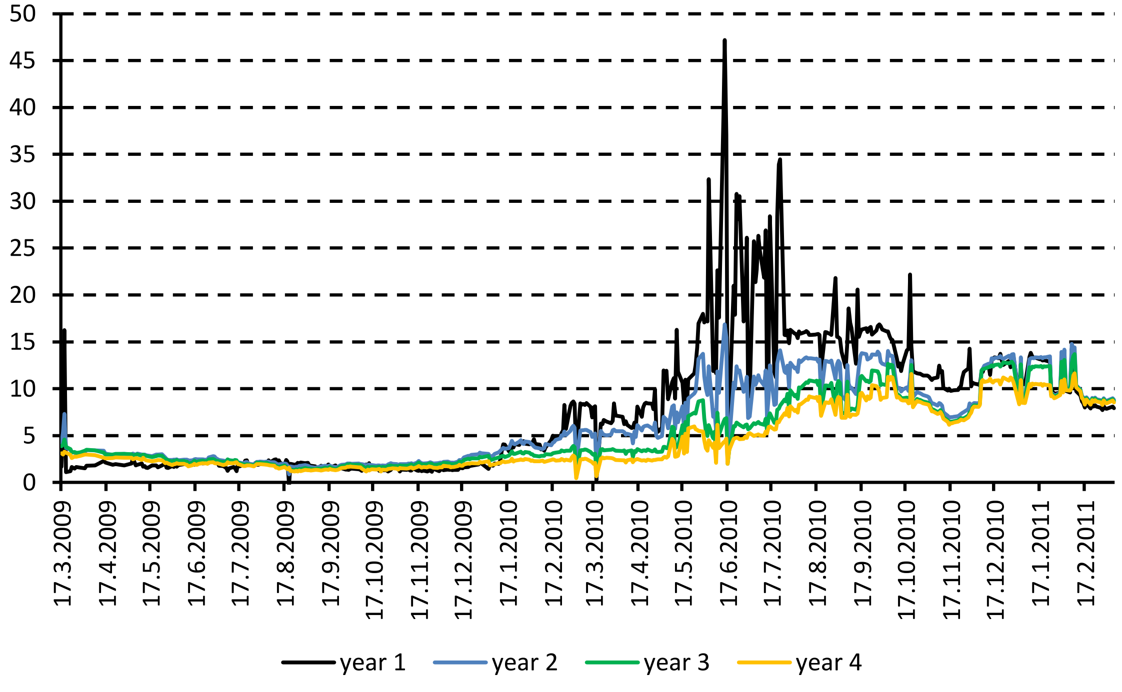
We will now try to select a proper time series for our next step which will be the analysis of evolution of probability of default. The most desirable from the theoretical point of view it would be to measure the hazard rate at time 0, which is the current probability of default implied by the bond market as seen by the investors. We have to choose between more desired short time horizon and longer time horizon we have data for and therefore the estimates are more reliable for it. In following graphs we can see the evolution of hazard rates for several different time horizons.

Figure 18: Hazard rate at year 0 from 17 March 2009 till 9 March 2011



Source: Author's computations

Figure 19: Hazard rate at years 1 to 4 from 17 March 2009 till 9 March 2011



Source: Author's computations

The graphs show the evolution of the hazard rate through the observed time period for chosen time horizons. We can get those graphs by making a "slice" through the three-dimensional graphs of estimated hazard functions at some time horizon through observed time period. The result is that we obtain a hazard rate, in other words the probability of default of Greek government at some time horizon given that the default did not occur in earlier time horizon. This hazard rate is then evolving in time from 17 March 2009 to 9 March 2011.

To quickly interpret the estimated probabilities we can also show how the estimates could be used in practice. Let's take as an example 9 March 2011, last observed day. Let us assume that we want to calculate a total probability that Greece will default within 2 years from that day. At that day the hazard rate for year 0 was almost 0, for year 1 it was 7.9 % and for year 2 approximately 8.8 %. For a very quick estimate we can use discrete approach instead of continuous one. We know that hazard rate is probability of default at given time given that the default did not happen before. The probability that the default would occur in the 1st year would be roughly 7.9 %, because there was 0 probability it would happen before. But it is now 7.9 % that it will happen in year 1, so the probability that it will happen in year 2 is just approximately (1-0.079) × 0.088 = 8.1 %. So the probability that the Greek government will survive 2 years is roughly (1-0.079) × (1-0.081) = 84.6 %. The probability of default within 2 years is then approximately 15.4 %.

We can see that the evolution of hazard rate at year 0 is different from other horizons. The rates are much higher and are much more concentrated around certain periods. The longer the horizon is the lower the rates in crisis periods and they tend to be slightly higher in the pre-crisis period. It shows that in the period of crisis hazard function tend to be of inverted, hyperbolic, shape. The big difference between zero horizon and longer horizons confirms our idea suggested above that we should not use the zero horizon for our further analysis, because the zero horizon is affected by the disadvantages of our method. To make our results more reliable we will use four time horizons, years 1 until 4, for our analysis. Now we can begin to test our hypotheses.

Hypothesis 1: 11 November 2009 was the trigger point of the crisis.

We mean by the trigger point of the crisis the point in time when the market-implied probability of default of Greek government started to grow. It is in fact the moment when investors saw that the imbalanced Greek fiscal policy can lead to unsustainable situation. 1 November 2009 was chosen based on the historical chapter 1.2.1. It was a day when the official EU document was released updating the estimate of 2010 deficit showing it is expected to be almost doubled and the document also concluded the poor effort done by the government to cope with the budget. Both information were new and important bad news which make it possible to think that that day was the trigger point of the crisis.

At first the trend was estimated by the OLS method and then the Chow test was run to test the trend of hazard rates for structural break on 11 November 2009. Following table summarize all tests.

Table 6: Chow tests for structural break on 11 November 2009

	restricted model			unrestricted model					
horizon	**constant**	**trend parameter**	**R^2**	**constant**	**first trend parameter**	**split dummy parameter**	**second trend parameter**	**R^2**	**Chow test p-value**
1	0.0051 (0.5964)	0.0345 (0.0031)	43.57 %	2.4971 (0.4129)	-0.0080 (0.0042)	-1.3193 (2.0850)	0.0396 (0.0075)	45.77 %	1.1e-020
2	0.3894 (0.4123)	0.0259 (0.0018)	69.01 %	3.2888 (0.2101)	-0.0131 (0.0024)	-4.2258 (0.8486)	0.0432 (0.0038)	73.94 %	8.7e-049
3	-0.0214 (0.3992)	0.0227 (0.0015)	73.14 %	3.1222 (0.1438)	-0.0132 (0.0018)	-6.2259 (0.5374)	0.0451 (0.0027)	83.31%	5.4e-066
4	-0.3108 (0.3682)	0.0208 (0.0013)	74.94 %	2.6632 (0.0951)	-0.0108 (0.0012)	-6.4896 (0.4349)	0.0420 (0.0019)	88.07 %	7.8e-112

Note: there are standard errors in the brackets below the estimated parameters

Source: Author's computations

We can see that we can highly significantly reject the Chow test's null hypothesis in all four cases. It means that we should rather use the unrestricted model with structural break than restricted model. We have to bear in mind that the exact location of structural break on 11 November 2009 is, however, not guaranteed, but it is not possible to reject it. If we ran the test on several other dates we would possibly see that the null hypothesis would be rejected also. But we can say that it is not true that the 11 November 2009 is not the trigger point of the Greek crisis. Together with the evidence of events which took place on 11 November 2009 described in the historical part of the thesis we can say it is at least reasonable to consider 11 November 2009 the trigger point of the crisis. For purposes of further analysis we will use this day as the day when the crisis begun.

Hypothesis 2: The probability of default of Greek government during the Greek fiscal crisis of 2010 rose significantly.

We will now assume that the crisis begun on 11 November 2009. Using the OLS method we will test whether there is a significant slope of a trend during the crisis. We will apply this procedure on all four time horizons as before. The estimated simple models are shown in the following table.

Table 7: Models of trend of hazard rates at years 1 to 4 from 11 November 2009 until 9 March 2011

	model of trend			
horizon	**constant**	**trend parameter**	$\mathbf{R^2}$	**p-value**
1	1,1778 (2,0438)	0,0316 (0,0062)	18.85 %	7,3e-007
2	-0,9370 (0,8236)	0,0301 (0,0030)	55.21 %	2,4e-021
3	-3,1037 (0,5172)	0,0318 (0,0021)	74.95 %	6,2e-041
4	-3,8264 (0,4231)	0,0312 (0,0015)	82.99 %	2,0e-059

Note 1: there are standard errors in the brackets below the estimated parameters

Note 2: time variable begins from 144, which is 11 November 2009

Source: Author's computations

The p-value in the table is the p-value of a t-test with the null hypothesis that the trend parameter estimate is zero. If we reject the null hypothesis we can conclude that the trend parameter is significantly distinct from zero. We can see that for all time horizons the estimate of trend slope is positive and highly significant. We can conclude that the probability of default rose significantly during the Greek crisis.

Hypothesis 3: The probability of default of Greek government fell significantly after the announcement of the aid package for Greek government.

The aid package for Greek government was announced on 25 March 2010, it however did not have a concrete form, which it gained on 11 April 2010. We will test both dates for the decrease in the hazard rate at years 1 to 4. We will test a short-run behavior of the hazard rate, so we will test only 30 observable days following the tested dates for negative slope of trend estimate using OLS method, which should be sufficiently short period to represent short-run behavior, still long enough for statistical reasons. Following two tables show the results of testing.

Table 8: Models of trend of hazard rates at years 1 to 4 from 26 March 2010 until 10 May 2010 (30 observations)

	model of trend			
horizon	**constant**	**trend parameter**	**R^2**	**p-value**
1	-27,6921 (10,3200)	0,1426 (0,0419)	39.66 %	0,0020
2	-9,5429 (5,3014)	0,0614 (0,0215)	35.37 %	0,0081
3	-5,8852 (5,3140)	0,0379 (0,0217)	25.21 %	0,0911
4	-5,2621 (4,4714)	0,0314 (0,0182)	25.68 %	0,0954

Note 1: there are standard errors in the brackets below the estimated parameters

Note 2: time variable begins from 235, which is 26 March 2010

Source: Author’s computations

Table 9: Models of trend of hazard rates at years 1 to 4 from 12 April 2010 until 21 May 2010 (30 observations)

	model of trend			
horizon	**constant**	**trend parameter**	**R^2**	**p-value**
1	-35,9117 (9,0776)	0,1743 (0,0359)	38.09 %	4,1e-05
2	-20,2444 (4,7929)	0,1030 (0,0187)	46.84 %	7.0e-06
3	-22,2538 (5,6062)	0,1019 (0,0220)	50.17 %	7,6e-05

4	-20,7735 (5,0746)	0,0923 (0,0199)	53.69 %	7,4e-05

Note 1: there are standard errors in the brackets below the estimated parameters

Note 2: time variable begins from 244, which is 12 April 2010

Source: Author's computations

If we look at the results for the first time period, after the first announcement of possible aid package, we can reject the hypothesis of falling hazard rates for all time horizons, because the trend slope estimate is for the first two cases positive and significantly different from zero and for years 3 and 4 we cannot say they are different from zero on widely used 5 % level of significance. The results for the second date, after the aid package was specified better, are even more convincing with lower p-values and higher slope parameters.

Hypothesis 4: The probability of default rose gradually even before the crisis.

We will test this hypothesis using OLS estimation method of trend from the beginning of observation period, 17 March 2009, until the beginning of the crisis on 11 November 2009. If the trend will be negative, we will reject the hypothesis. We will again test the trend time horizons of 1 to 4 years of hazard rate. Following table summarizes the results.

Table 10: Models of trend of hazard rates at years 1 to 4 from 17 March 2009 until 11 November 2009

	model of trend			
horizon	**constant**	**trend parameter**	$\mathbf{R^2}$	**p-value**
1	2,4981 (0,4214)	-0,0080 (0,0043)	6.58 %	0,0640
2	3,2804 (0,1982)	-0,0129 (0,0022)	56.12 %	2,3e-08
3	3,1131 (0,1271)	-0,0130 (0,0015)	72.89 %	2,8e-14
4	2,6568 (0,0826)	-0,0107 (0,0010)	78.45 %	7,4e-05

Note: there are standard errors in the brackets below the estimated parameters

Source: Author's computations

The results suppose we should reject the hypothesis that the probability of default rose gradually even before the crisis. For the first time horizon we cannot say the slope is different from zero and in all other cases it is significantly negative. It means that the hazard rate implied by the bond markets even tended to decline before the crisis.

4.6. Advantages and disadvantages of the method

For our purposes we needed a method which would have daily data available for the estimation of evolution of probability of default. The used method, unlike many other methods, was able to match this criterion using reliable daily data from bond markets. Because we needed the estimates to be run on each day of the very long observation period of 474 days, the method which would offer simple enough computation procedure was needed. Even though the method used is relatively parsimonious, the computations using available computer were very time consuming, however still feasible, which is another advantage of the method. Byström and Kwon (2005) also state that one of the main advantages when we use bond-based parsimonious methods is that we rely only on the present market data, so “it reflects the present and not the past”.

There are also several disadvantages of the method. The main disadvantage seem to be the above discussed unrealistic behavior of the hazard rate for short time horizons, because we do not observe any bonds with such a short time to maturity. It led to unrealistically high probability of default at time 0 higher than 100 % for some time periods. Due to that we had to omit using the current probability of default in further analysis and we had to use only hazard rates for longer time horizons to try to describe the evolution of probability of default.

4.7. Conclusions of the research

The research part of the thesis tried to pinpoint several interesting features of the Greek crisis. The first hypothesis served mainly as a supplementary hypothesis for further testing. It was shown that it is reasonable to consider 11 November 2009 as a trigger point of the crisis. It is important to say that this day the crisis was not created, it only started to be reflected by the bond market. The real causes of the crisis originate many years before this date. The rising bond market implied default risk of Greek government was just a sign that the bad fiscal situation of a government gone too far and investors became to worry about the possible default.

We also asked in the fourth hypothesis if investors became to worry about the situation gradually even before this trigger point. It was shown that they did not. The implied hazard rates were even slowly lowering. It can be a sign that bond markets are short sighted to a certain degree. The danger had to surpass some notional level to investors to become to worry about the situation.

The results of testing of hypothesis 2 showed that the hazard rates rose significantly during the Greek crisis, so investors evaluated bonds in such a manner that they believed that the fiscal crisis of Greece may lead to default more and more probably. From the testing of hypothesis 3 we can see that even the introduction of the aid package did not lead to the calming of the markets.

Summary

In the first chapter we described the history of the Greek fiscal crisis. We saw that the recent world economic crisis was not the real cause of the crisis in Greece. The world economic crisis was just the catalyzer of long term problems with fiscal policy in Greece which accelerated the process. The real causes of the crisis go back as far as to 1970s and 1980s, to the period when the government debt was built up. We also tried to find the most palpable problems of Greek contemporary economy related to the fiscal deficit. We saw that the Greek government should pay attention at first to the tax evasion, shadow economy and high and rising unemployment rate.

In the second chapter we studied the methodology of using bond market information for evaluation of probability of default of Greek government. We described simple parsimonious method, which estimates the evolution of the hazard function of government bonds through the selected period in several steps. At first, using daily data from coupon bond market data we estimate the zero coupon bond yield curve in Nelson-Siegel parametric form for a studied country and its benchmark, Greece and Germany in our case. Then we imposed three important assumptions. At first, we assumed that the recovery rate of bonds in case of credit default would be zero, so that the creditors would not get anything in the case of default. This unrealistic assumption was imposed in order to both simplify the calculations and enable the estimates to be fully comparable during the studied time period. We also assume that the default risk is the only type of risk a bond bears and that we are in a risk-neutral environment. After those simplifications we were able to easily obtain the hazard function estimates as an instantaneous forward credit spread calculated using the estimated parameters of zero coupon bond yield curves of a studied country and its benchmark.

In the third chapter we discussed a possible use of the credit default swaps for evaluation of the credit risk of a government. The advantage of the presented method is the possibility to estimate both hazard rate and recovery value, not only hazard rate as by the previous method. The practical use of the method is, however, complicated due to the fact that CDS data are not easily obtained as CDS are OTC contracts.

In the fourth chapter the methodology introduced in the second chapter is applied on the case study of Greece. The hazard function is estimated for each day from 11 November 2009 until 9 March 2011 where the data were available for both Greece and Germany, totaling to 474 days. We used a sample of 34 German and 20 Greek government bonds denominated in EUR. The data were retrieved from the Reuters Wealth Manager online application and adjusted for calculations using VBA. The estimation was done in the R program using the package called termstrc. After the estimation we have revealed the drawback of the used method. The estimated evolution of the hazard rate at zero horizon showed to be very unstable in time and unrealistically high in some cases, exceeding 100 %. It can be caused by the lack of bonds with a very short time to maturity in the sample and by the shape of used Nelson-Siegel curves. It is why we had to use only longer-time-horizon hazard rates to estimate the evolution of the probability of default and we also did not calculate the total probability of default, we just analyzed the hazard rates one by one. We studied the evolution of hazard rates for 1 to 4 year time horizons in one year steps through the whole period of 474 days.

In the analytical part of the study we found that probability of Greece, using our method, rose significantly from 11 November 2009, which is the date we discussed why and tested that it can be considered the beginning of the recent Greek crisis. Surprisingly, even the introduction of the aid package for Greece, consisting of a huge amount of EUR 110 billion loan facility, showed not to be able to convince investors and did not lower the probability of default of Greek government. But the most interesting finding was that before the crisis the probability of default had even lowered and then it suddenly changed its trend upward, even though the Greek fiscal problems were founded on the policy changes in 1970s and 1980s, as shown in chapter 1. It is why we can believe that bond markets are short-sighted and do not reflect the long term problems well.

There are several possible further research questions which can be studied about the Greek fiscal crisis. At first, a better model could be introduced, which would provide a more realistic estimate of the evolution of the hazard function, but still remaining parsimonious. We have to mention that even using the model used in this thesis is relatively computationally demanding, because the estimation procedure is computed for many days. Any further important complication of the model could make it unusable in practice. It would be also interesting to use the method using CDS information and to compare the results with the results from the bond market based estimation. It could be also interesting to extend the research to several other countries and to make a comparative study of Greece, Ireland, Italy, Portugal and Spain, for example and also, among others, see if the estimation problems of the used method are only country specific or if they would cause problems generally.

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List of appendices

Appendix 1: Government debt in EU 27 countries (in % of GDP)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EU (27 countries)	61.9	61.0	60.4	61.9	62.2	62.8	61.5	58.8	61.8	74.0
Austria	66.5	67.1	66.5	65.5	64.8	63.9	62.1	59.3	62.5	67.5
Belgium	107.9	106.6	103.5	98.5	94.2	92.1	88.1	84.2	89.6	96.2
Bulgaria	74.3	67.3	53.6	45.9	37.9	29.2	21.6	17.2	13.7	14.7
Cyprus	48.7	52.1	64.6	68.9	70.2	69.1	64.6	58.3	48.3	58.0
Czech Republic	18.5	24.9	28.2	29.8	30.1	29.7	29.4	29.0	30.0	35.3
Denmark	52.4	49.6	49.5	47.2	45.1	37.8	32.1	27.4	34.2	41.4
Estonia	5.1	4.8	5.7	5.6	5.0	4.6	4.4	3.7	4.6	7.2
Finland	43.8	42.5	41.5	44.5	44.4	41.7	39.7	35.2	34.1	43.8
France	57.3	56.9	58.8	62.9	64.9	66.4	63.7	63.8	67.5	78.1
Germany	59.7	58.8	60.4	63.9	65.8	68.0	67.6	64.9	66.3	73.4
Greece	**103.4**	**103.7**	**101.7**	**97.4**	**98.6**	**100.0**	**106.1**	**105.0**	**110.3**	**126.8**
Hungary	55.0	52.0	55.6	58.4	59.1	61.8	65.7	66.1	72.3	78.4
Ireland	37.8	35.6	32.2	31.0	29.7	27.4	24.8	25.0	44.3	65.5
Italy	109.2	108.8	105.7	104.4	103.8	105.8	106.6	103.6	106.3	116.0
Latvia	12.3	14.0	13.5	14.6	14.9	12.4	10.7	9.0	19.7	36.7
Lithuania	23.7	23.1	22.3	21.1	19.4	18.4	18.0	16.9	15.6	29.5
Luxembourg	6.2	6.3	6.3	6.1	6.3	6.1	6.7	6.7	13.6	14.5
Malta	55.9	62.1	60.1	69.3	72.3	70.1	63.4	61.7	63.1	68.6
Netherlands	53.8	50.7	50.5	52.0	52.4	51.8	47.4	45.3	58.2	60.8
Poland	36.8	37.6	42.2	47.1	45.7	47.1	47.7	45.0	47.1	50.9
Portugal	50.5	52.9	55.6	56.9	58.3	63.6	63.9	62.7	65.3	76.1
Romania	22.5	25.7	24.9	21.5	18.7	15.8	12.4	12.6	13.4	23.9
Slovakia	50.3	48.9	43.4	42.4	41.5	34.2	30.5	29.6	27.8	35.4
Slovenia	:	26.8	28.0	27.5	27.2	27.0	26.7	23.4	22.5	35.4
Spain	59.3	55.5	52.5	48.7	46.2	43.0	39.6	36.1	39.8	53.2
Sweden	53.6	54.4	52.6	52.3	51.1	50.8	45.0	40.0	38.2	41.9
United Kingdom	41.0	37.7	37.5	39.0	40.9	42.5	43.4	44.5	52.1	68.2

Source: Eurostat Statistics Database. Accessed 23 November 2010

Appendix 2: Net lending (+)/net borrowing (-) of general government in EU 27 countries (in % of GDP)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EU (27 countries)	0.6	-1.4	-2.5	-3.1	-2.9	-2.5	-1.5	-0.9	-2.3	-6.8
Austria	-1.7	0.0	-0.7	-1.4	-4.4	-1.7	-1.5	-0.4	-0.5	-3.5
Belgium	0.0	0.4	-0.1	-0.1	-0.3	-2.7	0.2	-0.3	-1.3	-6.0
Bulgaria	-0.3	0.6	-0.8	-0.3	1.6	1.9	1.9	1.1	1.7	-4.7
Cyprus	-2.3	-2.2	-4.4	-6.5	-4.1	-2.4	-1.2	3.4	0.9	-6.0
Czech Republic	-3.7	-5.6	-6.8	-6.6	-3.0	-3.6	-2.6	-0.7	-2.7	-5.8
Denmark	2.3	1.5	0.4	0.1	2.1	5.2	5.2	4.8	3.4	-2.7
Estonia	-0.2	-0.1	0.3	1.7	1.6	1.6	2.4	2.5	-2.8	-1.7
Finland	6.8	5.0	4.0	2.4	2.3	2.7	4.0	5.2	4.2	-2.5
France	-1.5	-1.5	-3.1	-4.1	-3.6	-2.9	-2.3	-2.7	-3.3	-7.5
Germany	1.3	-2.8	-3.7	-4.0	-3.8	-3.3	-1.6	0.3	0.1	-3.0
Greece	**-3.7**	**-4.5**	**-4.8**	**-5.6**	**-7.5**	**-5.2**	**-5.7**	**-6.4**	**-9.4**	**-15.4**
Hungary	-3.0	-4.0	-8.9	-7.2	-6.4	-7.9	-9.3	-5.0	-3.7	-4.4
Ireland	4.8	0.9	-0.3	0.4	1.4	1.6	2.9	0.0	-7.3	-14.4
Italy	-0.8	-3.1	-2.9	-3.5	-3.5	-4.3	-3.4	-1.5	-2.7	-5.3
Latvia	-2.8	-2.1	-2.3	-1.6	-1.0	-0.4	-0.5	-0.3	-4.2	-10.2
Lithuania	-3.2	-3.6	-1.9	-1.3	-1.5	-0.5	-0.4	-1.0	-3.3	-9.2
Luxembourg	6.0	6.1	2.1	0.5	-1.1	0.0	1.4	3.7	3.0	-0.7
Malta	-6.2	-6.4	-5.5	-9.8	-4.7	-2.9	-2.7	-2.3	-4.8	-3.8
Netherlands	2.0	-0.2	-2.1	-3.1	-1.7	-0.3	0.5	0.2	0.6	-5.4
Poland	-3.0	-5.3	-5.0	-6.2	-5.4	-4.1	-3.6	-1.9	-3.7	-7.2
Portugal	-2.9	-4.3	-2.8	-2.9	-3.4	-6.1	-4.1	-2.8	-2.9	-9.3
Romania	-4.7	-3.5	-2.0	-1.5	-1.2	-1.2	-2.2	-2.6	-5.7	-8.6
Slovakia	-12.3	-6.5	-8.2	-2.8	-2.4	-2.8	-3.2	-1.8	-2.1	-7.9
Slovenia	-3.7	-4.0	-2.5	-2.7	-2.2	-1.4	-1.3	0.0	-1.8	-5.8
Spain	-1.0	-0.6	-0.5	-0.2	-0.3	1.0	2.0	1.9	-4.2	-11.1
Sweden	3.7	1.6	-1.2	-0.9	0.8	2.3	2.3	3.6	2.2	-0.9
United Kingdom	3.6	0.5	-2.1	-3.4	-3.4	-3.4	-2.7	-2.7	-5.0	-11.4

Source: Eurostat Statistics Database. Accessed 23 November 2010

Appendix 3: Real GDP change (in %)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EU (27 countries)	3.9	2	1.2	1.3	2.5	2	3.2	3	0.5	-4.2
Austria	3.7	0.5	1.6	0.8	2.5	2.5	3.6	3.7	2.2	-3.9
Belgium	3.7	0.8	1.4	0.8	3.2	1.7	2.7	2.9	1	-2.8
Bulgaria	5.7	4.2	4.7	5.5	6.7	6.4	6.5	6.4	6.2	-4.9
Cyprus	5	4	2.1	1.9	4.2	3.9	4.1	5.1	3.6	-1.7
Czech Republic	3.6	2.5	1.9	3.6	4.5	6.3	6.8	6.1	2.5	-4.1
Denmark	3.5	0.7	0.5	0.4	2.3	2.4	3.4	1.6	-1.1	-5.2
Estonia	10	7.5	7.9	7.6	7.2	9.4	10.6	6.9	-5.1	-13.9
Finland	5.3	2.3	1.8	2	4.1	2.9	4.4	5.3	0.9	-8
France	3.9	1.9	1	1.1	2.5	1.9	2.2	2.4	0.2	-2.6
Germany	3.2	1.2	0	-0.2	1.2	0.8	3.4	2.7	1	-4.7
Greece	**4.5**	**4.2**	**3.4**	**5.9**	**4.4**[p]	**2.3**[p]	**4.5**[p]	**4.3**[p]	**1.3**[p]	**-2.3**[p]
Hungary	4.9	3.8	4.1	4	4.5	3.2	3.6	0.8	0.8	-6.7
Ireland	9.7	5.7	6.5	4.4	4.6	6	5.3	5.6	-3.5	-7.6
Italy	3.7	1.8	0.5	0	1.5	0.7	2	1.5	-1.3	-5
Latvia	6.9	8	6.5	7.2	8.7	10.6	12.2	10	-4.2	-18
Lithuania	3.3	6.7	6.9	10.2	7.4	7.8	7.8	9.8	2.9	-14.7
Luxembourg	8.4	2.5	4.1	1.5	4.4	5.4	5	6.6	1.4	-3.7
Malta	:	-1.6	2.6	-0.3	0.9	4	3.6	3.7	2.6	-2.1
Netherlands	3.9	1.9	0.1	0.3	2.2	2	3.4	3.9	1.9	-3.9
Poland	4.3	1.2	1.4	3.9	5.3	3.6	6.2	6.8	5.1	1.7
Portugal	3.9	2	0.7	-0.9	1.6	0.8	1.4	2.4	0	-2.6
Romania	2.4	5.7	5.1	5.2	8.5	4.2	7.9	6.3	7.3	-7.1
Slovakia	1.4	3.5	4.6	4.8	5.1	6.7	8.5	10.5	5.8	-4.8
Slovenia	4.4	2.8	4	2.8	4.3	4.5	5.9	6.9	3.7	-8.1
Spain	5	3.6	2.7	3.1	3.3	3.6	4	3.6	0.9	-3.7
Sweden	4.5	1.3	2.5	2.3	4.2	3.2	4.3	3.3	-0.4	-5.1
United Kingdom	3.9	2.5	2.1	2.8	3	2.2	2.8	2.7	-0.1	-5

p = provisional value

Source: Eurostat Statistics Database. Accessed 23 November 2010

Appendix 4: The Chow's test for regression stability

We will use Baltagi (2008) in the appendix. We can consider two following regressions:

$$y_1 = X_1\beta_1 + u_1$$

$$y_2 = X_2\beta_2 + u_2$$

X_1 and X_2 are observation matrices of dimensions $n_1 \times k$ and $n_2 \times k$, respectively. Both n_1 and n_2 must be greater than k. Then the unrestricted regression is defined as:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} X_1 & 0 \\ 0 & X_2 \end{pmatrix} \begin{pmatrix} \beta_1 \\ \beta_2 \end{pmatrix} + \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$$

The null hypothesis then states that all regression coefficients are equal for both equations:

$$H_0\colon \beta_1 = \beta_2 = \beta$$

The restricted regression is defined as:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} X_1 & 0 \\ 0 & X_2 \end{pmatrix} \beta + \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$$

For the hypothesis testing we need to compute URSS and RRSS, residual sum of squares from unrestricted and restricted regression. There is also a possibility to use dummy variable approach used also in the thesis. Dummy variable (called split dummy in the thesis) denotes if the observation comes from the first or second observation matrix. The equation is then transformed into:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} \beta_1 + \begin{pmatrix} 0 \\ X_2 \end{pmatrix} (\beta_2 - \beta_1) + \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$$

The test statistics of the Chow test is then:

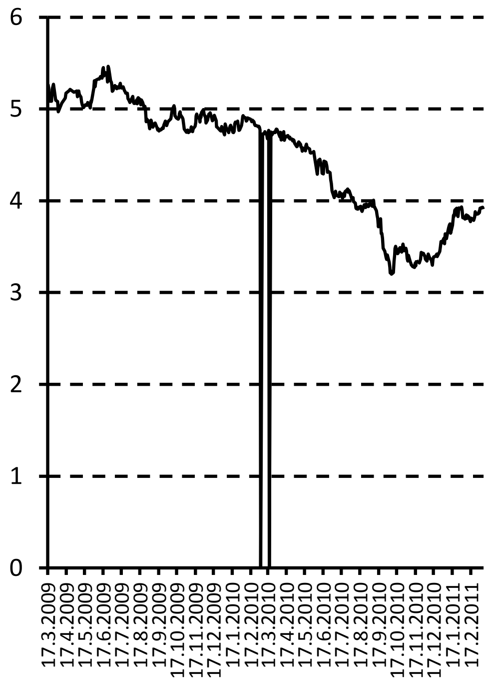
$$F = \frac{\frac{RRSS - URSS}{k}}{\frac{URSS}{n_1 + n_2 - k}}$$

Under the null hypothesis the F statistics follows the F distribution with k and $n_1 + n_2 - k$ degrees of freedom.

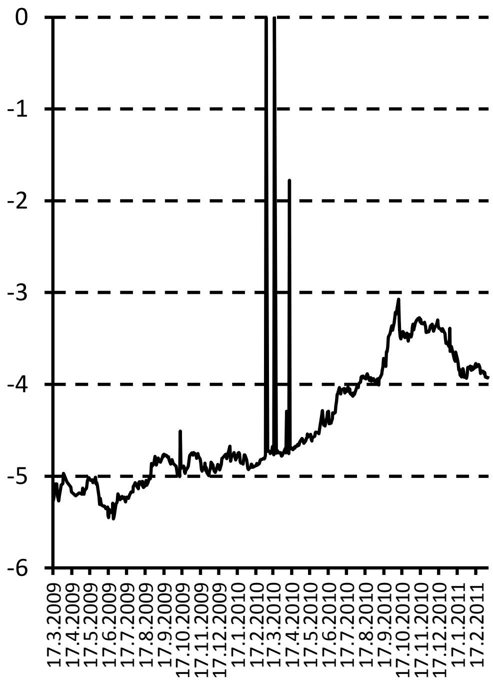
Appendix 5: Estimated parameter vector beta for Germany and Greece using no constraints on tau and with maturity range from 0 to 20

Germany

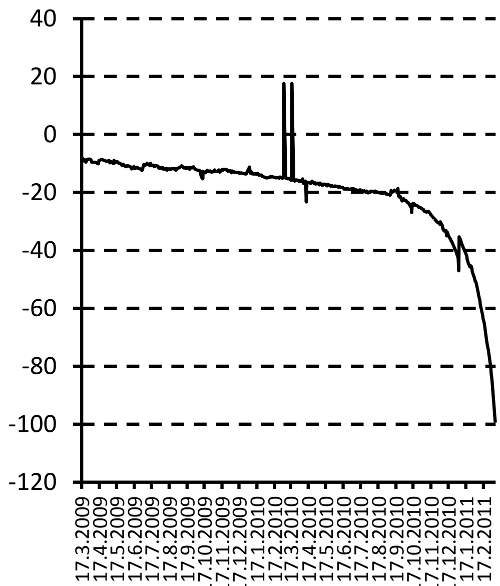
Beta 0



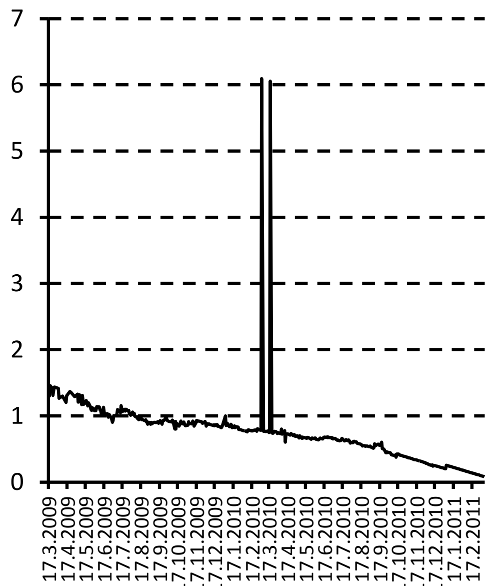
Beta 1



Beta 2

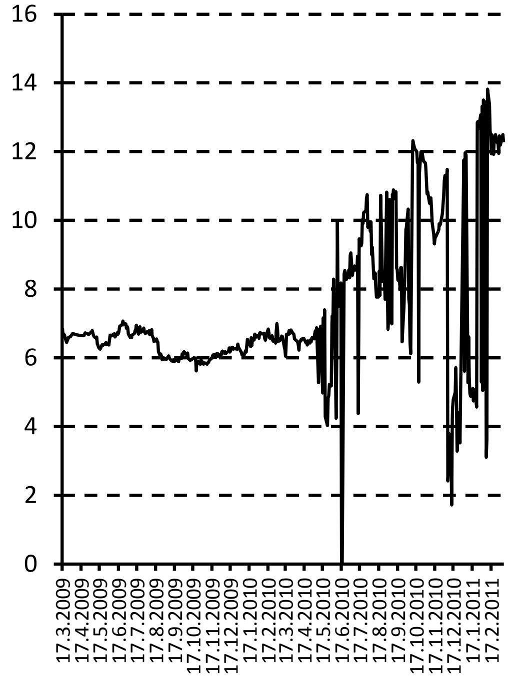


Tau

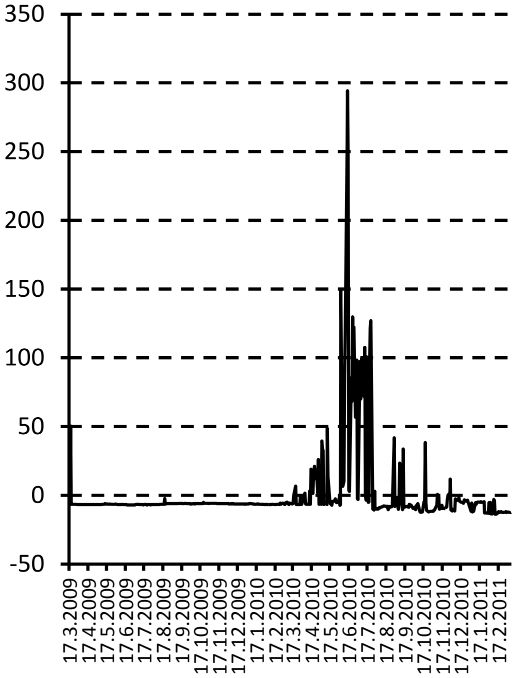


Greece

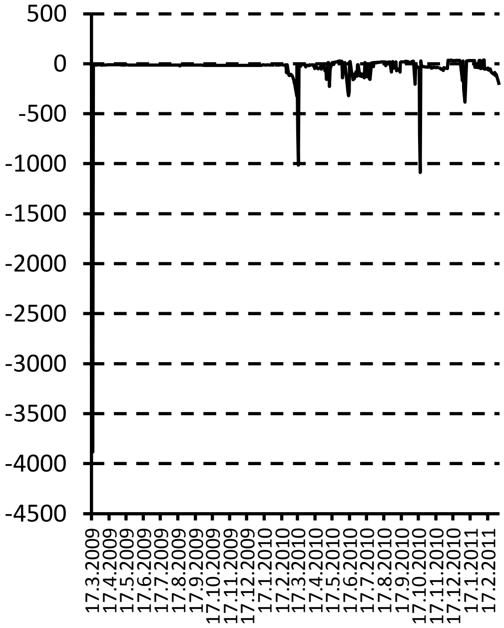
Beta 0



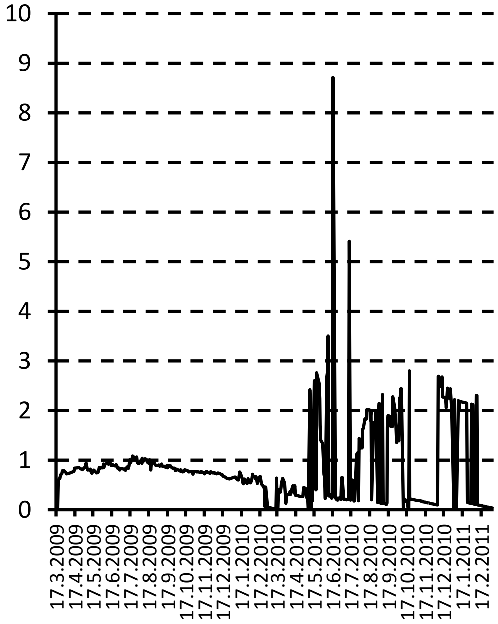
Beta 1



Beta 2



Tau



Source: Author’s calculations